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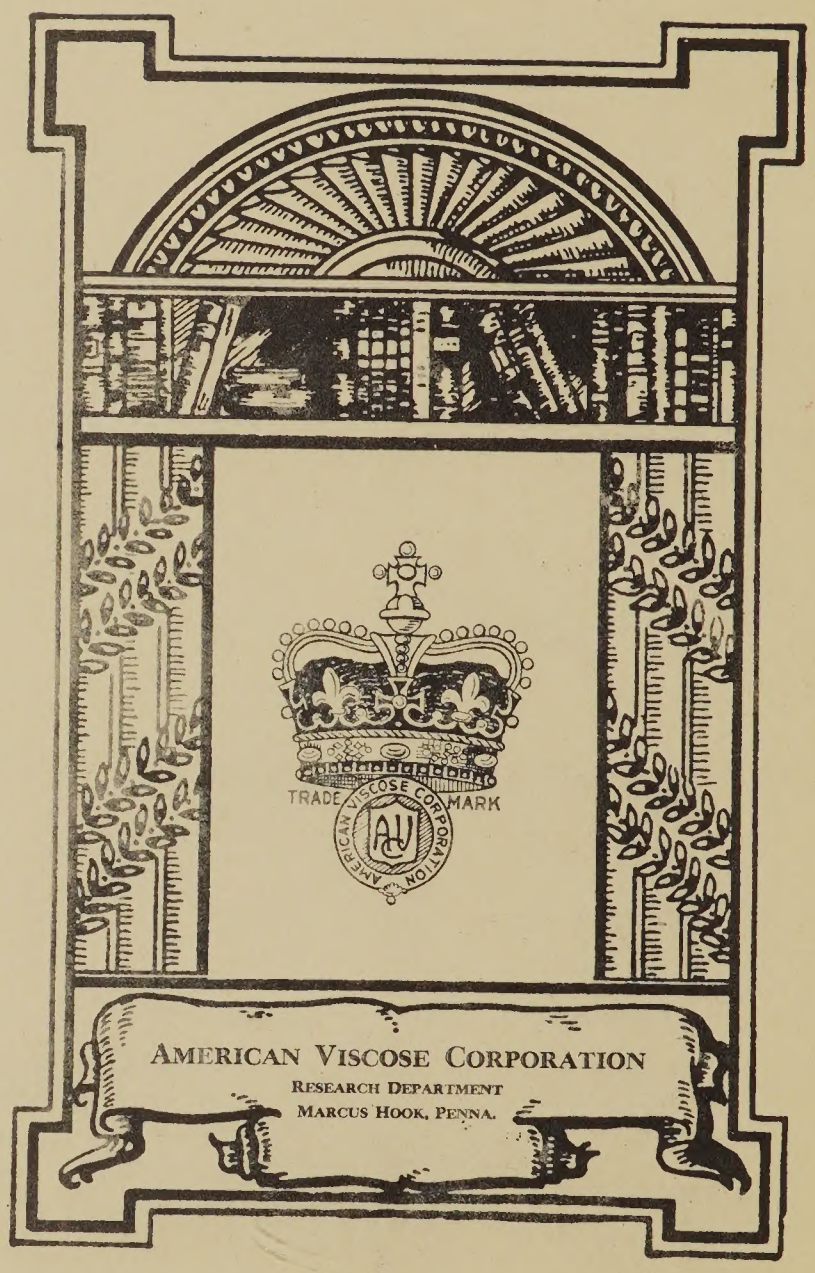

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TRANSACTIONS OF THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

RECENT ADVANCES IN THE AMERICAN SULPHUR INDUSTRY

By RAYMOND F. BACON and HAROLD S. DAVIS

Read at the New Orleans Meeting, December 6, 1920

Sulphur plays a more basic rôle in chemical industry than any other element. Either as elementary sulphur or combined as a metallic sulphide, it is the source of all sulphuric acid. Hence any changes in the sulphur industry should be of great interest to the chemical engineering profession.

America now dominates the sulphur industry and virtually all the American sulphur is produced by three companies—viz., the Union Sulphur Co., the Freeport Sulphur Co. and the Texas Gulf Sulphur Co. These three companies produce not only virtually all the sulphur used in the United States but also a considerable surplus which is exported. The only other sulphur which normally enters the American market in quantity comes from Japan[1] and its percentage calculated on the consumption of the United States is small and is not likely to increase. Rising costs of living have meant much higher wages in Japan, as well as in other parts of the world; in fact, the percentage increase has probably been greatest in Japan, due not only to world conditions affecting all countries but to the rising standards of living of the Japanese. These facts, together with present higher transportation costs, will make it increasingly difficult for Japanese sulphur to compete on our Pacific Coast with the American product.

Expansion of Industry During War

During the World War, and especially after America's entry into it, the demand for sulphur grew enormously. Some time previous

[1] However, no Japanese sulphur is being imported into this country at the present time.

to our declaration of war consideration had been given by a certain group of New York capitalists to the opening up of the sulphur deposit (known as the "Big Dome") located near Matagorda, Tex. These plans were hastened to realization by our Government's need and demand during the war for the maximum production from every possible source of sulphur. The plans eventuated in the formation of the Texas Gulf Sulphur Co., which, however, did not get its plants into operation until after the armistice. Production has been practically continuous since the company first mined sulphur on March 19, 1919. The plant of this company, which has been described elsewhere,[2] was designed to have a capacity of 1,000 tons of sulphur per day, but for months at a time during the past year it has produced on an average 2,000 tons per day. The total production for the year 1920 exceeds 800,000 long tons, while in all probability the production for 1921 will be the largest of any sulphur company in the world. The possible daily production with the present plant, under favorable conditions, could be forced to three or four thousand tons per day. The deposit contains upward of ten million tons of sulphur; and a brief description of its character is as follows:

Description of Big Dome at Matagorda

The main deposit has a diameter of about 4,000 ft. and is situated 800 to 1,000 ft. below the surface of the ground. The sulphur occurs in an almost flat stratum, whose general shape is like that of a flat-topped umbrella. Above the sulphur stratum is an unconsolidated sediment consisting of bands of shale, gumbo and boulders. Below is a layer of salt and gypsum, and then a layer of salt of undetermined but very considerable thickness. The sulphur content of the deposit runs quite uniform with a slightly higher percentage of sulphur on one side of the dome. The mining operations are carefully checked, and a large-sized model of the deposit enables the engineers constantly to visualize what is taking place underground.

Production and Stocks Exceed Post-War Normal Demand

At the time the Texas Gulf Sulphur Co. entered the market the situation was about as follows: The Union Sulphur Co. had on top of the ground, in unsold stock of sulphur, upward of one million tons

[2] *Chem. & Met. Eng.*, vol. 20, No. 4, pp. 186–188. *Eng. Min. J.*, vol. 107 (1919), pp. 555–7.

and the Freeport Sulphur Co. had several hundred thousand tons. The normal consumption of sulphur in the United States had been between four and five hundred thousand tons per annum, which quantity could be readily supplied by the two older companies.[3] A new sulphur company entering the market with a large production of sulphur was therefore compelled to pursue one of two policies—either to attempt to obtain a share of the business by cutting prices or to place the sulphur in markets which had not hitherto used sulphur; in other words, to increase the sulphur consumption of the country.

With reference to the first possibility, competition based on cut-throat slashing of prices always has proved disastrous to the whole industry. Moreover, the mining of sulphur by the Frasch process, to be carried out economically, must be conducted on a very large scale, so that even if a company under the conditions outlined above had obtained a third of a possible 500,000-ton consumption, this would not have insured profitable operation. The company has chosen what is surely the wiser course, in attempting to place its sulphur by increasing the total consumption in the industries.

It was possible to do this owing to the prevailing economic conditions. The United States had in recent years consumed annually, for the manufacture of sulphuric acid, upward of 500,000 tons of sulphur in the form of pyrites, most of which came from Spain. The older sulphur companies, either because of some agreement with the pyrites importers or because of a desire to hold the price of sulphur at a certain level, had not attempted seriously in past years to substitute sulphur for pyrites as the raw material of sulphuric acid manufacture. Importation of Spanish pyrites, due to war transportation conditions, fell off very seriously during the war years. This caused many producers of sulphuric acid to discard the pyrites roasters and to install sulphur-burning equipment, while new producers in this field erected plants which were almost entirely so equipped. The new company was able to obtain its fair proportion of the new business and the net result has been that the total consumption of sulphur of the United States during the past year has been upward of 1,000,000 tons, as compared with a normal consumption in recent years of about half that figure.

[3] It may be stated, in passing, that any economic data given regarding either the Union Sulphur Co. or the Freeport Sulphur Co. are subject to the usual statement on advertisements of bond sales; that is, "they are gathered from sources we believe to be reliable, but are not guaranteed by us."

Pyrites Versus Sulphur as a Source of SO_2

It is interesting, in this connection, to give just a little history, for if the subject is examined it is found that in the early days of sulphuric acid manufacture all the sulphuric acid of Europe, excepting Nodhausen acid, was made from brimstone. This includes the period from about 1750 to 1839, when pyrites first was used commercially for the manufacture of sulphuric acid in England. This use of pyrites was due to the fact that the Neapolitan Government in 1838 granted a monoply for the exportation of sulphur to Taix & Co., of Marseilles, which firm immediately raised the price of sulphur from $25 to $70 per ton. By so doing, it killed the goose that laid the golden egg, for pyrites was substituted immediately for sulphur in most European countries and the era of high-priced sulphur was but short lived. The loss of this market was a permanent setback to Sicilian sulphur.

The subsequent history of the sulphur industry is one of violent ups and downs. If one considers this history up until some time after Frasch made America a factor in the business, it will be noted that it has been characterized at all times by short periods of prosperity, followed by a short-sighted, selfish, destructive competition on the part of certain interests. Following this would come a period of such marked depression as to threaten the life of the entire industry, and it would be necessary for some governmental or other outside agency to excercise pressure to get the producers together on a common-sense basis and thus gradually put the industry again on its feet.[4] Since the time when Frasch made possible America's sulphur industry the stability of the whole industry has been much greater. While at the present time there is an extremely lively competition among the companies for business, there is every reason to believe that American common sense, spirit of fair play, and co-operation will prevent this competition going to the extent of threatening the industry itself, as has happened many times in the past. Present indications are that all the sulphur companies are pursuing an enlightened policy, in that all are doing more or less research and development work having as its ultimate object the opening up of broader markets for sulphur, of which sulphuric acid manufacture affords but one.

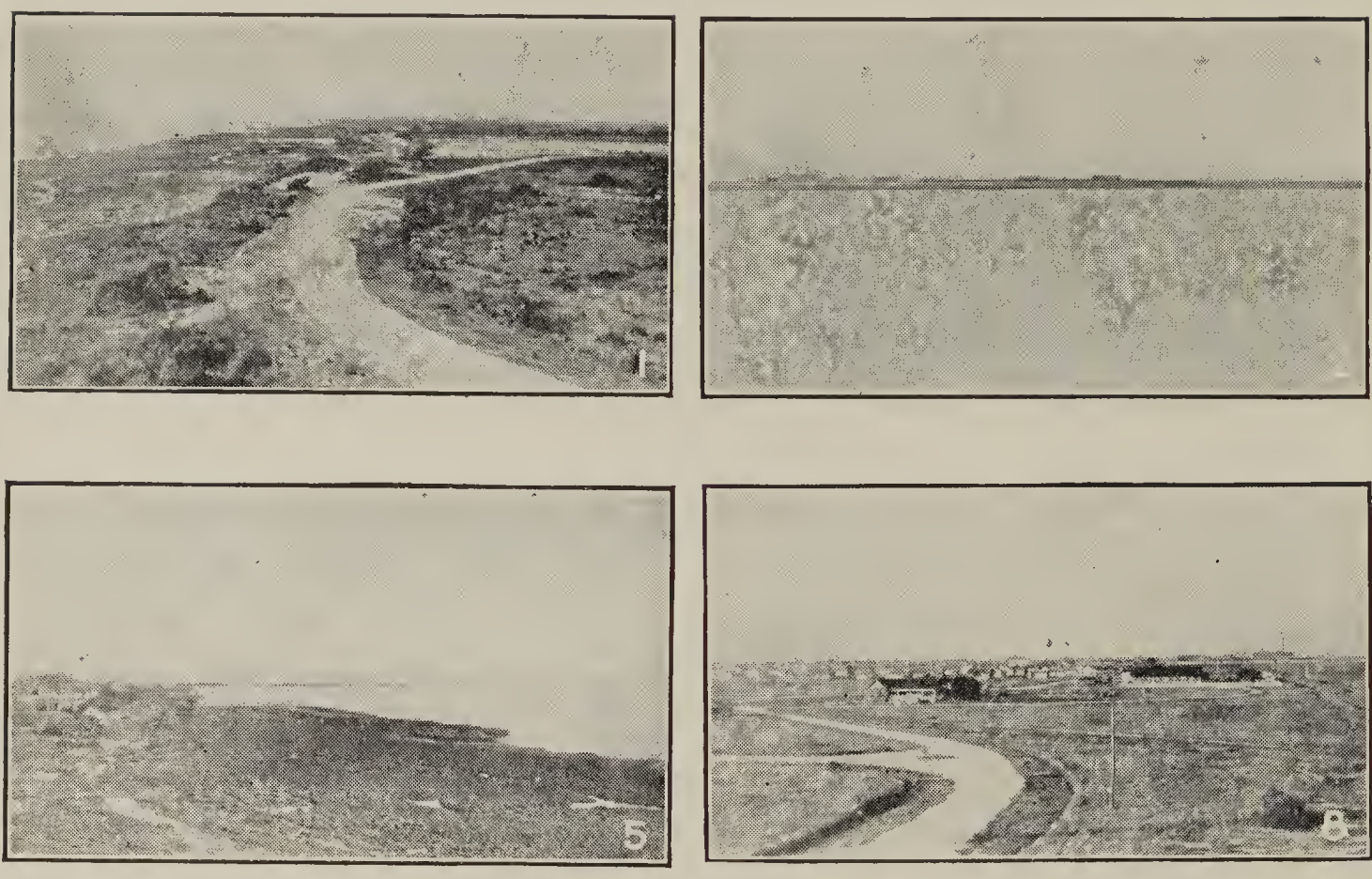
[4] In this connection, see Frasch, Perkin Medal Address, *Met. & Chem. Eng.*, vol. 10, No. 2, pp. 73–82, and *J. Ind. Eng. Chem.*, vol. 4 (1912), p. 139.

Advantages of Sulphur Over Pyrites

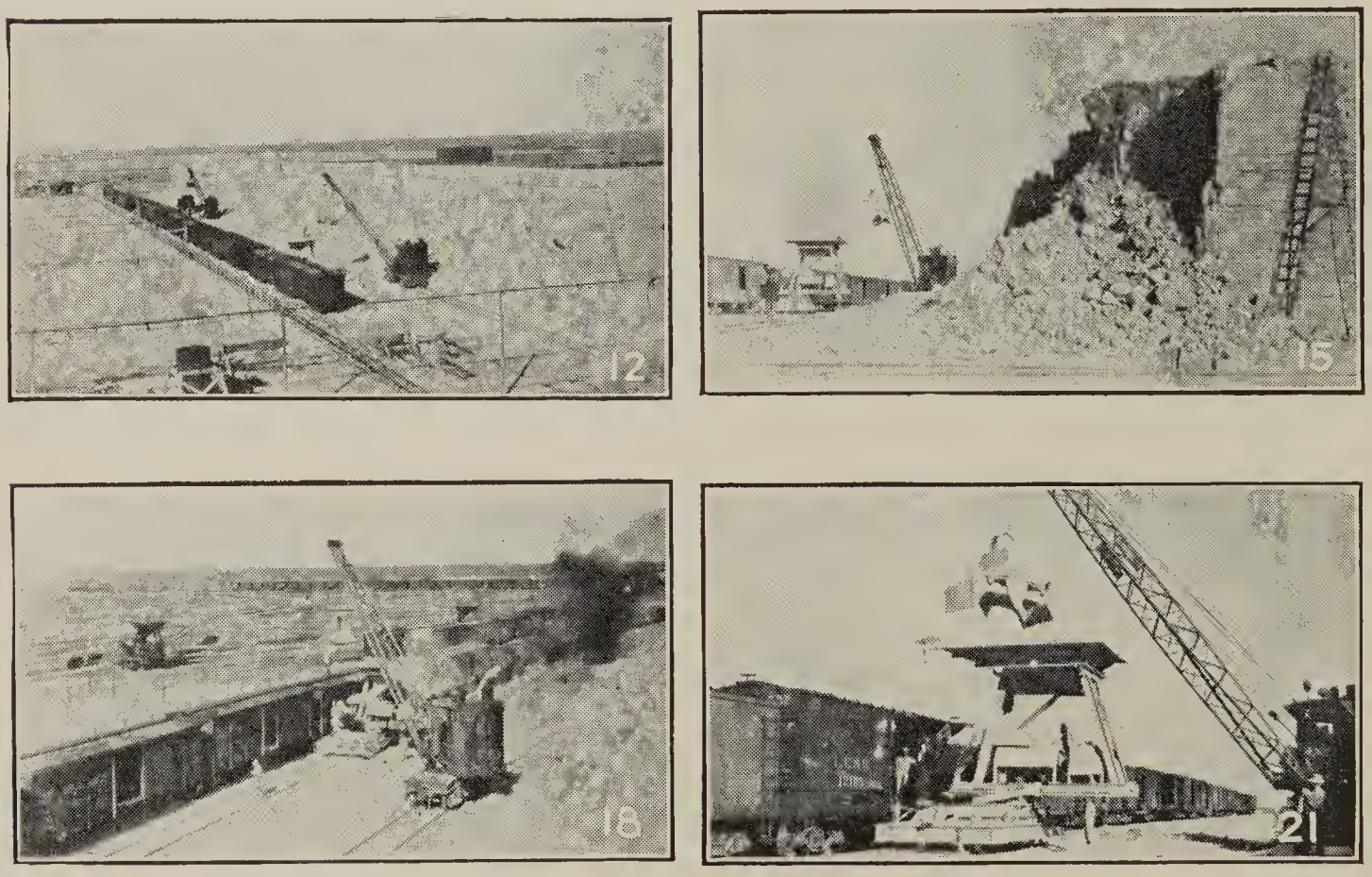
For sulphuric acid manufacture sulphur has many very marked advantages over pyrites. Using pyrites means handling into the works a comparatively large quantity of material, its slow combustion in expensive roasters, a certain inevitable dust nuisance and the disposal of a large tonnage of cinder. As against this, sulphur of less than one half the weight of pyrites for a given tonnage of acid produced is handled into the works, is burned cleanly in inexpensive equipment and leaves no residues to be taken care of. Sulphur is constant in composition, and its freedom from arsenic and other impurities allows the production of a purer acid. It is also claimed that, in practice, the burning of sulphur means a higher rate of production for a given size of lead chamber space.

These acknowledged advantages of the use of sulphur over pyrites for sulphuric-acid manufacture have been demonstrated by the willingness of acid producers to pay a higher price per unit for elementary sulphur than for combined sulphur in the form of pyrites. An example of this is the fact that one of our largest and best organized chemical companies, in making a large contract, chose sulphur over pyrites for sulphuric-acid manufacture, where the differential in offered prices was 8c. per unit of sulphur.

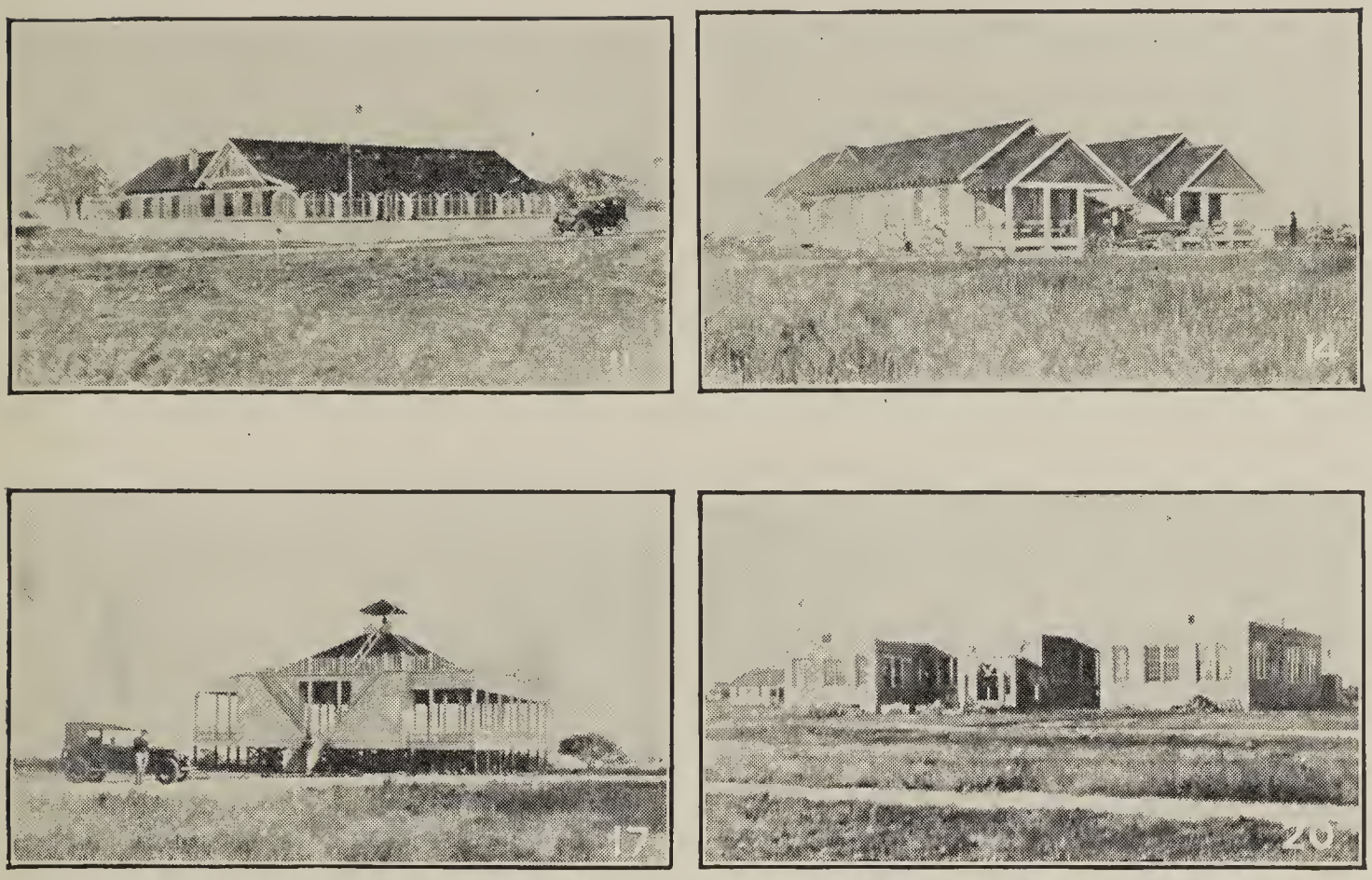
When one considers the present high prices of labor, the uncertainty of the copper market and the fact that sulphur may be purchased in a competing market, from concerns which have large stocks on hand, so that delivery is certain, it would seem to be a wise business policy to use sulphur rather than pyrites for sulphuric-acid manufacture even with a very large differential in price. This is especially true when one considers the other side of the situation—namely, that in buying imported pyrites the consumer is putting himself at the mercy of one large set of interests which, while it may at the present time offer pyrites at low prices and even below actual cost, will almost certainly at some time in the future reap its profit by much higher prices. It is said that imported pyrites has been offered for large contracts in this country at about 10c. per unit of sulphur, ex-vessel, Atlantic seaboard, while at the same time pyrites was selling in England, much nearer the base of supplies, at 20c. to 22c. per unit of sulphur. It reminds one somewhat of the tactics of Standard Oil in the old days before "trust-busting" became fashionable with politicians; and everyone knows that those who bought cheaply when the company was extinguishing a competitor never



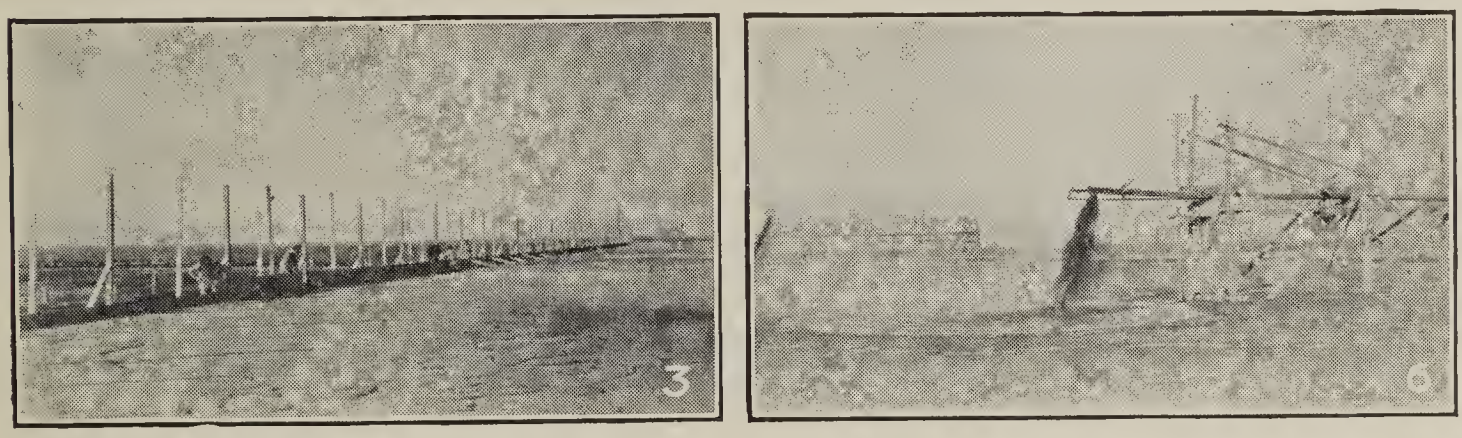
General Views Showing Topography, Figs. 1, 2, 5, 8.

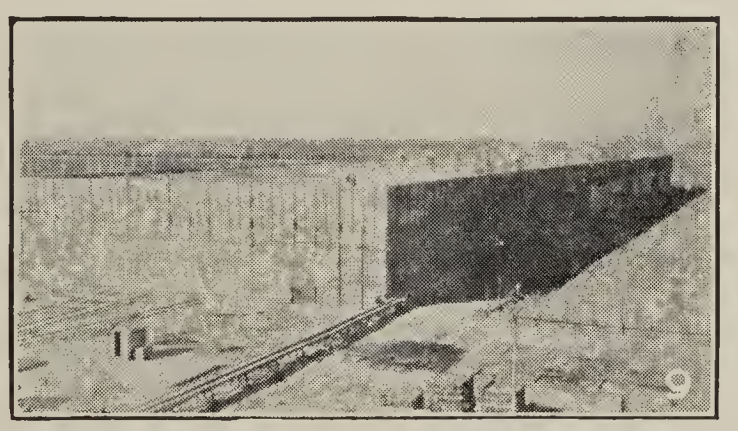


Method of Loading for Shipment, Figs. 12, 15, 18, 21.

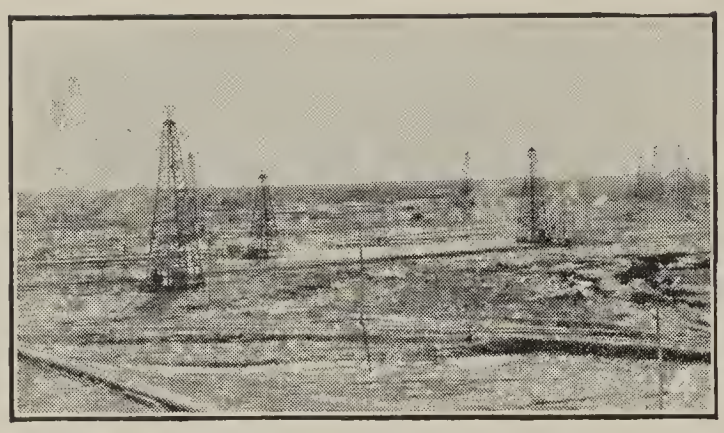


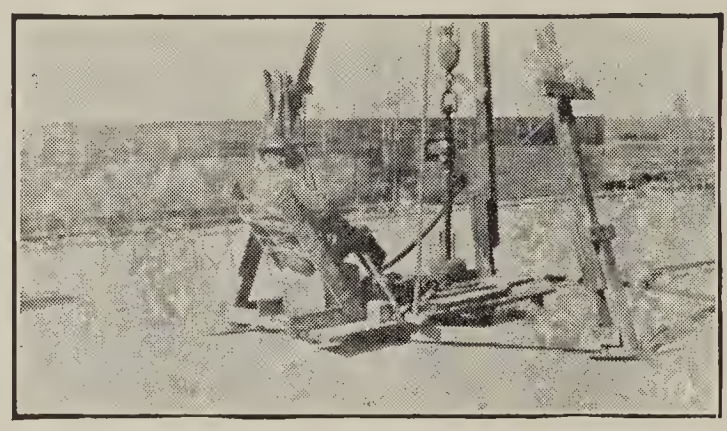
Houses, Pavilion and Hospital, Figs. 11, 14, 17, 20.



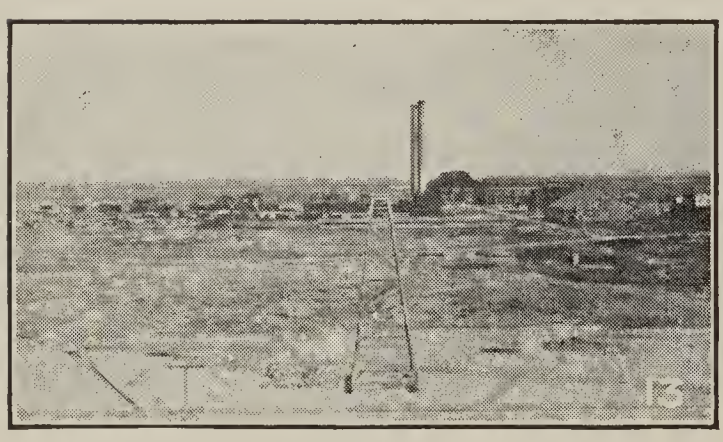


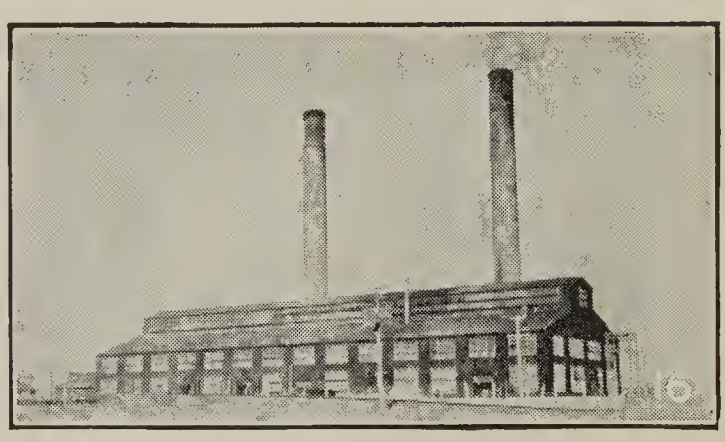
Sulphur Tank Storage System, Figs. 3, 6, 9.

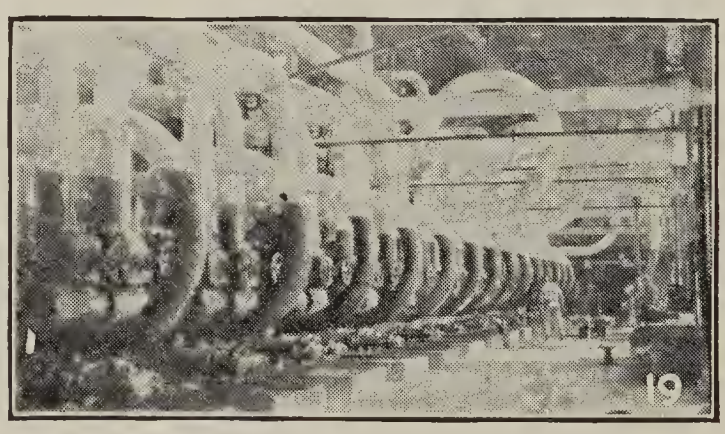




Well Driving Equipment, Figs. 4, 7, 10.







Exterior and Interior Views of Power House, Figs. 13, 16, 19.

reaped any permanent advantage, but later more than paid for temporary reductions in price.

Sulphur is today one of the few substances which have not risen in price since pre-war days. In fact, sulphur is cheaper today than at any other time in the history of the industry. The price for large contracts is about $20 per ton, Atlantic seaboard. This makes sulphur one of the cheapest raw materials available and should, it would seem, greatly extend its usefulness. Sulphur as mined and sold by all three companies is of remarkably high grade. In fact, many so-called C.P. chemicals do not possess the purity of crude sulphur, as sold by these companies. The sulphur is free from arsenic, selenium and tellurium, and often for days at a time wells will yield a product running higher than 99.9 per cent sulphur, as calculated on a moisture-free basis; in fact, sulphur companies selling the crude sulphur on contracts guarantee the purity to be over 99 or 99½ per cent.

Effect of Traces of Petroleum on Combustion

One impurity occurring in traces in the sulphur of all three companies is oil. There is a dearth of information in the technical literature respecting the subject of oil in sulphur. Since the effect of this impurity is very interesting, it is appropriate to discuss it here. The peculiar effect of oil is its influence on the burning qualities and also on the color and odor of sulphur. *A priori*, one would not assume that mere traces of a combustible substance like petroleum oil could affect adversely the combustion of another combustible substance like sulphur, but such is indeed the case.

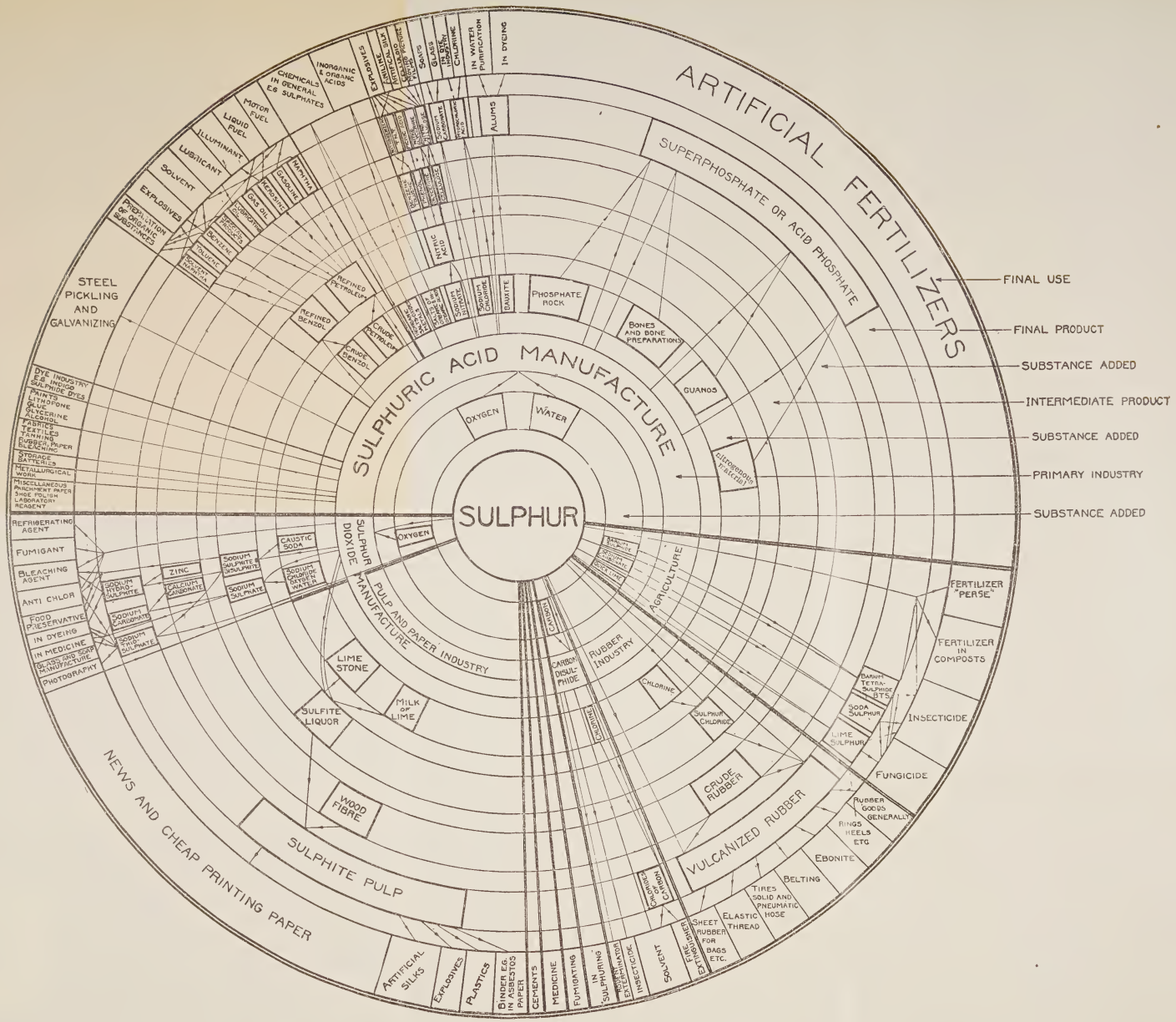
If one will make a simple experiment by attempting to burn two small lots of sulphur, one being chemically pure and the other containing 0.2 per cent of petroleum oil, he will note the following phenomena: The pure sulphur will burn quietly until it is totally consumed; the sulphur containing the oil will burn for a very short time, when it will be observed that a thin, elastic film is being formed over its surface. Very soon combustion is taking place only in spots, and within an exceedingly short time the flame goes out, although only a small percentage of the sulphur has been consumed. The explanation is quite simple. Sulphur and oil at a moderate temperature react together to form asphalt, and if the reaction is carried to completion the final result is carbon.

In the burning of sulphur containing oil the oil reacts with the

sulphur to form an asphaltic material, which quickly spreads as a film over the surface. The result, as combustion proceeds, is a film of carbon over the surface of the sulphur. The ignition temperature of carbon, or of the intermediate asphaltic material, is so much higher than that of sulphur itself or than the temperature developed during the burning of the sulphur that this film is not ignited and consequently the whole flame is extinguished.

The remedy for burning such sulphur is also quite obvious. If the devices for sulphur combustion are such as to agitate the surface of the burning sulphur or in any other way break this film of asphaltic material, no difficulty will be experienced. Acid manufacturers who use mostly modern types of sulphur burners, such as the rotary or cascade type, which allow the sulphur to drop from one level to another, have absolutely no difficulty in burning sulphur containing 0.2 per cent of oil, which figure represents more oil than any of the commercial sulphurs contain at the present time. On the other hand, many of the small paper-pulp manufacturers still adhere to types of burners in which the burning sulphur is more or less quiescent. With such a type there is no agitation of the burning liquid surface, so that some of these paper-pulp manufacturers have had difficulty in burning sulphur when they happened to obtain a shipment comparatively high in oil.

The sulphur deposits of all three operating companies are located in close proximity to oil fields. When a sulphur deposit is first opened some of the product may be high in oil, running as much as 0.2 per cent, but as production proceeds the oil becomes progressively lower until finally, for days at a time, it may amount to only 0.04 per cent which is totally negligible, even for burners which provide no agitation of the surface. We have assumed that hot water carried this small quantity of oil from small crevices in the oil-sand formation to the sulphur below when the well was first opened. After a region has become heated up by the hot water, these traces of oil are pretty well washed out; consequently, sulphur mined later in the same area is virtually free from it. Examination of drill cores of native sulphur showed such *in situ* sulphur to be oil-free. We are informed by ex-employees of the Union Sulphur Co. that this corresponds with the experiences of that organization in heating up any new area of sulphur ground. The examination of a very large number of samples of sulphur, representing the production of all three companies, has shown quite positively that none of their sulphur contains enough oil to cause any difficulty in its combustion with rotary


ARTIFICIAL FERTILIZERS
SUPERPHOSPHATE OR ACID PHOSPHATE
SULPHURIC ACID MANUFACTURE
SULPHUR
OXYGEN
WATER
PHOSPHATE ROCK
BONES AND BONE PREPARATIONS
GUANOS
NITROGENOUS FERTILIZERS
AGRICULTURE
FERTILIZER "PERSE"
FERTILIZER IN COMPOSTS
INSECTICIDE
FUNGICIDE
SULPHUR DIOXIDE
PULP AND PAPER INDUSTRY
LIME STONE
SULFITE LIQUOR
MILK OF LIME
WOOD FIBRE
SULPHITE PULP
NEWS AND CHEAP PRINTING PAPER
RUBBER INDUSTRY
CRUDE RUBBER
VULCANIZED RUBBER
RUBBER GOODS GENERALLY
RINGS HEELS ETC.
EBONITE
BELTING
TIRES SOLID AND PNEUMATIC HOSE
ELASTIC THREAD
SHEET RUBBER FOR BAGS ETC.
FILLING EXTENDING
CARBON DISULPHIDE
CHLORINE
SULPHUR CHLORIDES
BARIUM TETRA SULPHIDE BTS
SODA SULPHUR
LIME SULPHUR
SOLVENT
INSECTICIDE
FUMIGATING
MEDICINE
CEMENTS
PLASTICS
EXPLOSIVES
ARTIFICIAL SILKS
BINDER E.G. IN ASBESTOS PAPER
IN SULPHURING
STEEL PICKLING AND GALVANIZING
REFRIGERATING AGENT
FUMIGANT
BLEACHING AGENT
ANTI CHLOR
FOOD PRESERVATIVE
IN DYEING
IN MEDICINE
GLAZING AND SIZE MANUFACTURE
PHOTOGRAPHY
SODIUM HYPO-SULPHITE
SODIUM CARBONATE
SODIUM SULPHATE
ZINC
CALCIUM CARBONATE
SODIUM SULPHITE & SULPHATE
CAUSTIC SODA
SODIUM CHLORIDE OXYGEN WATER
ALUMS
IN DYEING
IN WATER PURIFICATION
CHLORINE
SALTS
GLASS
INORGANIC & ORGANIC ACIDS
CHEMICALS IN GENERAL E.G. SULPHATES
EXPLOSIVES
ARTIFICIAL SILK
MOTOR FUEL
LIQUID FUEL
ILLUMINANT
LUBRICANT
SOLVENT
EXPLOSIVES
PREPARATION OF ORGANIC SUBSTANCES
NAPHTHA
GASOLINE
KEROSENE
GAS OIL
BENZOLE
TOLUOLE
XYLOLE
SOLVENT NAPHTHA
REFINED PETROLEUM
REFINED BENZOL
CRUDE PETROLEUM
CRUDE BENZOL
NITRIC ACID
SODIUM NITRATE
SODIUM CHLORIDE
SALT CAKE
SODIUM CARBONATE
CAUSTIC SODA
CHLORINE
HYDROCHLORIC ACID
SODIUM SULPHATE
SODIUM SULPHITE
SODIUM HYPO-SULPHITE
ZINC
CALCIUM CARBONATE
SODIUM SULPHITE & SULPHATE
CAUSTIC SODA
SODIUM CHLORIDE OXYGEN WATER
DYE INDUSTRY E.G. INDIGO SULPHIDE DYES
PAINTS LITHOPONE GLUE GLYCERINE ALIZARINE
TEXTILES TANNING
RUBBER PAPER BLEACHING
STORAGE BATTERIES
METALLURGICAL WORK
MISCELLANEOUS ANALYTICAL PAPER SHOE POLISH LABORATORY REAGENT
FINAL USE
FINAL PRODUCT
SUBSTANCE ADDED
INTERMEDIATE PRODUCT
SUBSTANCE ADDED
PRIMARY INDUSTRY
SUBSTANCE ADDED

burners or other burners which agitate the surface of the burning sulphur during combustion. It is only very exceptionally that one will find a car of sulphur whose oil content is high enough to make difficulties in its combustion in a stationary type of burner.

Properties and Uses of Sulphur

Sulphur is now and is likely to be for some time one of our cheapest raw materials, and accordingly should and undoubtedly will find a much wider range of usefulness. It is by studying the physical and chemical properties of a substance that one first obtains ideas as to possible new uses therefor. The chief physical properties of sulphur are tabulated in Table I. The present tonnage uses of sulphur are presented in the chart. Those properties which suggest certain possible tonnage uses for sulphur are its very poor conductivity of heat and electricity, its resistance to being wetted by water and its inertness toward most acids, all of this combined with a fair degree of physical strength. These properties suggest heat-insulating materials, electrical insulators of various types, water- and acid-proof cements, and acid-proof construction materials.

As against the properties of sulphur which might make it very desirable for certain construction purposes are certain objectionable ones, such as its brittleness and its flammability. The brittleness can be overcome sufficiently for many purposes by making mixtures of sulphur with other materials, such as sand, asbestos, or paper pulp, or by reinforcing with wire screen. In many cases the flammability is not a serious objection.

A survey of the literature, especially the patents, on the subject of sulphur mixtures reveals that almost every conceivable thing has been suggested as a perfective admixture for sulphur to obtain a material which has all the air- and acid-resistant properties one could desire or to get a completely resistant kind of concrete useful in building. We have tested out most of the recipes which appeared to be promising and find as usual that the claims have been much overstated. However, the ordinary mixture of sand and sulphur which has been repeatedly mentioned in the literature has merits which should make it better known. The mixture which has seemed to us the best for most uses is that of 40 of sulphur and 60 of sand (parts by weight). The tensile strengths of sulphur-sand mixtures as measured in the usual manner for testing cement were as follows:

TENSILE STRENGTHS OF SULPHUR–SAND MIXTURES

Percentage of Sulphur by Weight	Tensile Strength, Lb. per Sq. In.
25	90
35	310
40	400
45	310
50	110
100	250

We have also used other fillers which have given tensile strengths of 800 and even 1,100 lb. measured in the same manner and have to a large extent overcome the brittleness of the sulphur in some of these mixtures. Sulphur-sand briquets kept for one year show no deterioration in strength. It is evident that the 40-60 sulphur-sand mixture can be used as an acid-resistant concrete, for making acid-resisting pipe, tanks, gutters, launders, etc. The manipulation of such a mixture is much like that of pouring concrete and is as follows:

Practical Manipulation. It is evident that the sand should contain no constituent which will be attacked by any material which is to come in contact with the finished product; for instance in the case of acid tanks it should be free from limestone or other acid-soluble constituents. If necessary, it should be washed and dried. The sulphur may be melted in a kettle with constant stirring and the sand, which has been heated separately, poured into it while the stirring is continued. Unless the sand is heated, it will lump when poured into the sulphur. When the material is thick enough (40 per cent sulphur and 60 per cent sand) it is ladled into the molds.

Considerable flexibility is possible in handling this material. For instance, a small tank was made which was 2 ft. square, 18 in. deep, and 2 in. thick. The mixture was poured into a wooden mold in twelve different lots. Although several of these lots had solidified before the next was poured upon them, nevertheless the resulting joints were strong. Apparently the hot mixture melts sufficient of the solidified part to form a solid joint. There was no contraction of the tank as a whole and no tendency to split in the mold. This mixture can be worked with a trowel, like mortar. It can also be reinforced by wire netting placed in the mold before it is poured. The specific gravity of a sulphur-sand mixture (40 :60) was found to be 2.46.

Weight of 1 cu. ft.	154 lb.
Weight of sulphur required per cu. ft.	62 lb.
Weight of sulphur required per cu. yd.	1,670 lb.

LXVI.—CHEMICAL AND PHYSICAL PROPERTIES OF SULPHUR

International Atomic Weight, 1921 = 32.06

Forms of Sulphur — **Sp. Gr.**

Crystalline

(*a*) Rhombic. Ordinary form, stable below 96° C. [205° F.]..... 2.07[1]

(*b*) Monoclinic. Stable above 96° C. [205° F.]..... 1.96[1]

(*c*) Milk of Sulphur. Formed, e.g., by action of dilute acids on polysulphides, generally called amorphous, but shown by Smith and Brownlee to be crystalline..... 2

There are several other modifications of crystalline sulphur of scientific interest but not of general importance.

Liquid. At 113° C. [235° F.]..... 1.81[1]

Contains Sulphur [liquid, soluble]..... S_λ

Sulphur [liquid insoluble or amorphous]..... S_μ

The proportion of S_λ to S_μ increases with the temperature.

Amorphous. S_μ [solid]..... 1.89[3]

Plastic Sulphur formed by heating sulphur above viscous stage, 162° C. or 324° F. and cooling quickly..... 1.88[3]

Elastic Sulphur formed by heating sulphur above 400° C. or 752° F. and pouring in a thin stream into liquid air. Its elastic properties are soon lost.

Black Sulphur. "When sulphur mixed with very little oil is thrown into a hot platinum dish, a black substance is obtained which has been looked on as a modification of sulphur. The product contains 55% of sulphur and 33% carbonaceous material."

—Watts, "Dictionary of Chemistry."

Vapor Density

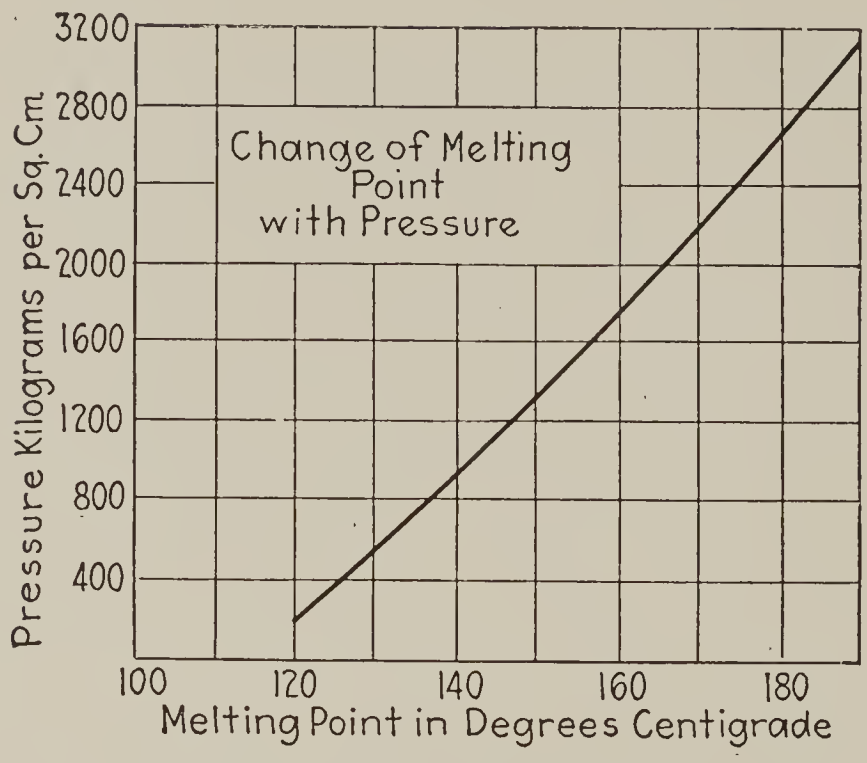
At B.P. corresponds approx. to formula..... S_8[13]

At 1000° C. corresponds approx. to formula..... S_2 [1832° F.]

MELTING POINT[1]

Type of Sulphur	Temperature C.	F.
Rhombic	112.8	235
Monoclinic	119.25	246.7

Natural freezing point S_λ and S_μ in equilibrium [96.3%S_λ 3.7%S_μ]. 110.2° C. = [230.4° F.]



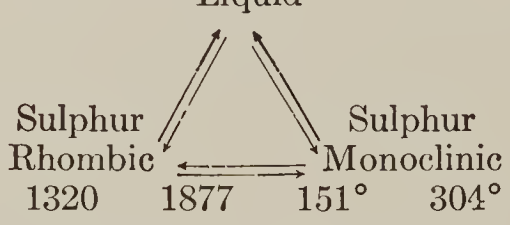
Change of M.P. with Pressure[1]

TRANSITION TEMPERATURE[1]

$S_{Monoclinic} \rightleftharpoons S_{Rhombic}$

Pressure		Temperature	
Kg./cm.²	Lbs./in.²	C.	F.
10.6	15	96°	204.8°
123	175	100	212.2
638	907	120	248
1,350	1,920	150	302

TRIPLE POINT



SPECIFIC HEAT[1]

Type of Sulphur	Temperature		Specific Heat
	C.	F.	
Rhombic.....	0–95°	32–203°	0.1751
Liquid.....	160–201	320–393	0.279
	201–233	393–451	0.331

HEAT OF COMBUSTION[1]

	G. cal. per g. Sulphur.	B. T. U. per. lb.
$S + O_2 \rightarrow SO_2$	2,200	3,960
$S \rightarrow H_2SO_3$ [dilute]	2,450	4,410
$S \rightarrow H_2SO_4$ [dilute]	4,450	8,010

HEAT OF VAPORIZATION[8]

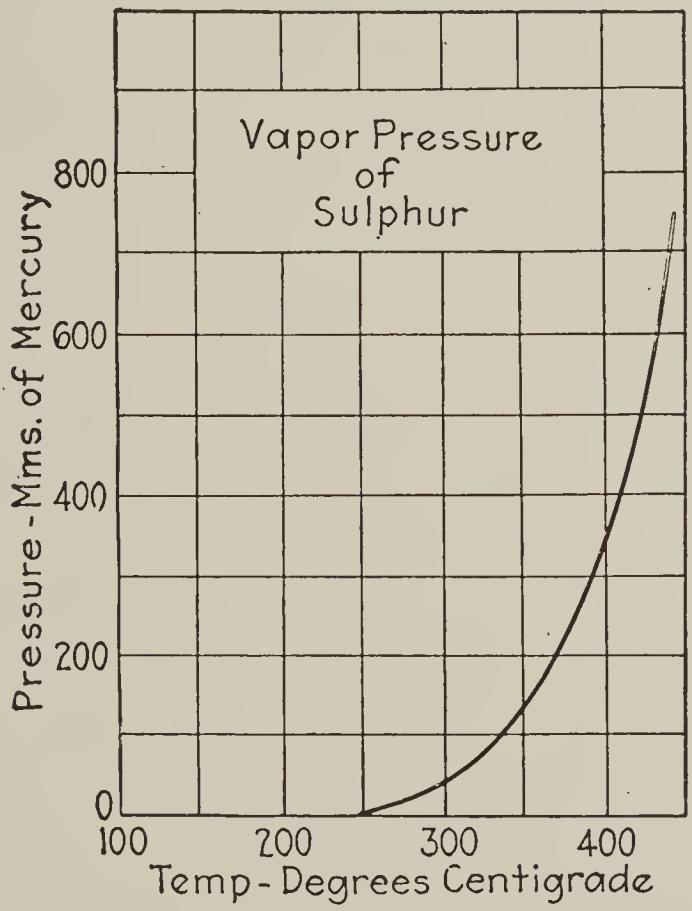
Temperature C.	Temperature F.	G. cal. per g.	B. T. U. per lb.
444.6°	832.3°	70 (approx.)	126

HEATS OF SOLUTION IN $C.S_2$[9]

	G. cal. per g.	B. T. U. per lb.
Dilute solution	−11.89	−21.4
Saturated solution	−11.55	−20.9

HEATS OF FUSION[10]

	G. cal. per g.	B. T. U. per lb.
Rhombic at 100° C. [212° F.]	14.9	26.8
Monoclinic at 100° C. [212° F.]	11.5	20.7
To form pure Liquid Sulphur [S_λ]		
from Rhombic	14.5	26.1
from Monoclinic	11.1	20.0



Vapor Pressure Curve[1]

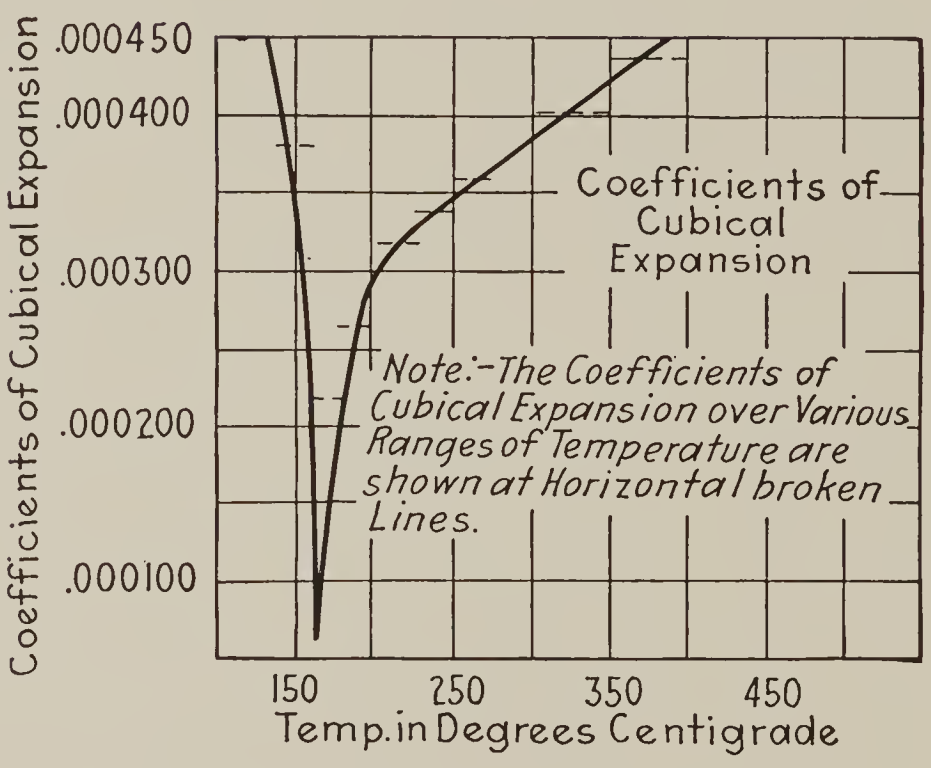
HEAT CONDUCTIVITY[1]

[Measured as the number of gram calories transmitted in 1 second through a plate 1 cm. thick and having surfaces 1 sq. cm. in area when opposite faces differ in temp. by 1° C.]

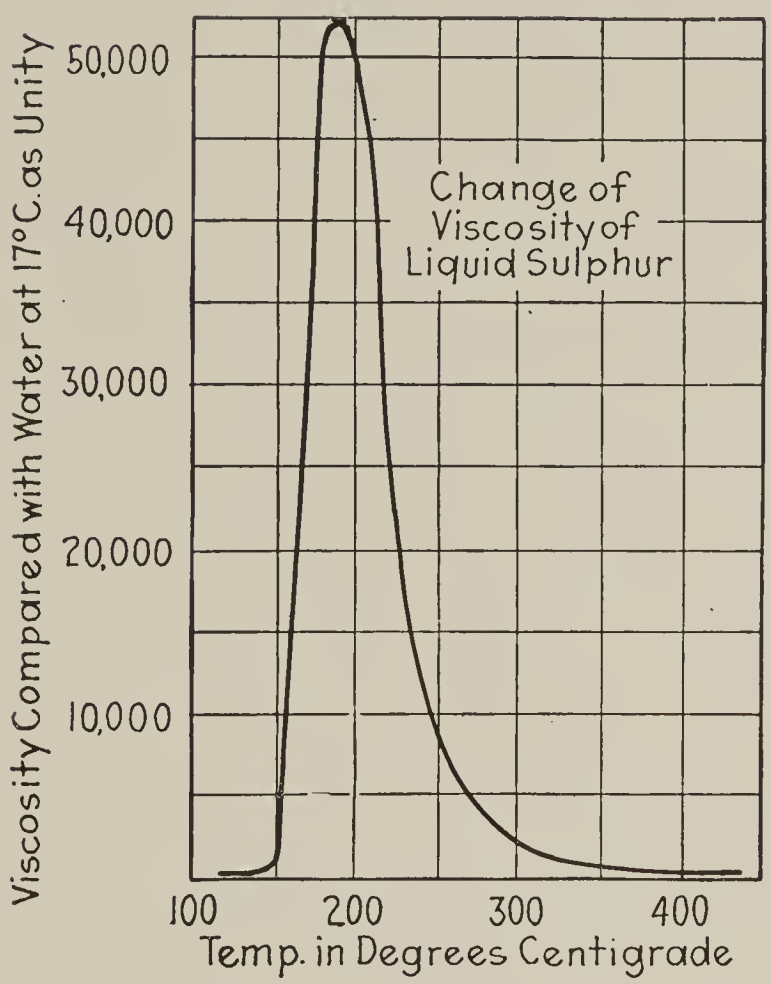
	20°–100° C. [68°–212° F.]	0.0006
Compare	Ice	0.002
	Copper	1.00

COEFFICIENT OF LINEAR EXPANSION[1]

Temperature C.	Temperature F.	Ex. Coeff.
0°–13°	32°–56°	0.000046
13 –50	56 –122	0.00007
50 –78	122 –173	0.00009
78 –97	173 –207	0.0002
97 –110	207 –230	0.001



Coefficients of Cubical Expansion at Different Temperatures[12]



Change in Viscosity with Temperature[1]

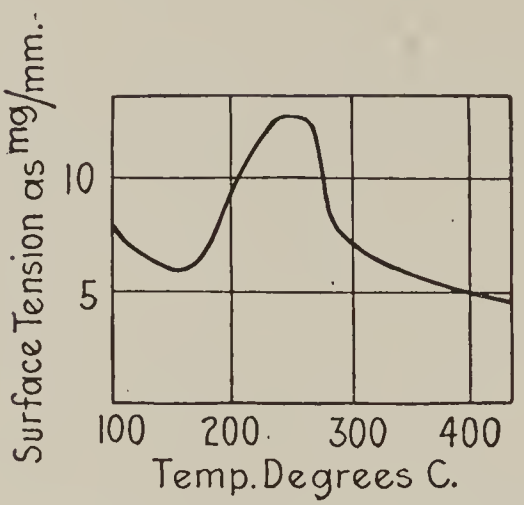
COMPRESSIBILITY[5]

Average fractional change of volume caused by 1 megabar change in pressure between 100–500 megabars, 0.0000125.

1 megabar = 0.987 Atmospheres

SURFACE TENSION[4]

Temperature C.	Temperature F.	Surface Tension mg. per mm.
120°	248	5.71
131	267.8	6.12
146	294.8	6.05
195	383	6.62



Approximate Curve of Surface Tension

ELECTRICAL CONDUCTIVITY

[Measured as reciprocal value of Resistivity in ohms of 1 cm. cube]

Temperature C.	Temperature F.	Conductivity[1]
22	72	1×10^{-17}
69	156	$.254 \times 10^{-15}$
115	239	$.105 \times 10^{-11}$
130	266	$.5 \times 10^{-10}$
430	806	$.1 \times 10^{-7}$
Compare		
Porcelain		1×10^{-14}
Mica		1×10^{-12}
Ebonite		1.5×10^{-11}

FRICTIONAL ELECTRICITY

When rubbed with practically any other substance, e.g., glass, fur, silk, wool or hard rubber, sulphur becomes charged with negative electricity.

SOLUBILITIES IN VARIOUS SOLVENTS[11]

Solvent	Temperature C.	Temperature F.	Solubility g. in 100 g. Solution
Amyl alcohol	95°	203°	1.5
	110	230	2.1
Aniline	89.5	193.1	8.3
	130	266	46.2
Benzene	25	77	2.1
	70	158	8.0
Carbon disulphide	−20	−4	10.5
	−10	14	13.5
	0	32	18
	20	68	29.5
	50	122	59
	100	212	92
Carbon tetrachloride	25	77	0.86

Chloroform	22	71.6	1.2
Coal tar oil			
Sp. gr. 0.87	15	59	2
	100	212	13
Sp. gr. 1.02	15	59	6.5
	110	230	53.5
Ethyl ether	23.5	74.3	0.97
Linseed oil	15	59	0.4
	160	320	9.0
Olive oil	15	59	2.2
[Sp. gr. 0.885]	130	266	30
Sulphur chloride	0	32	11
	55.2	131.4	43
	86	186.8	89
Phenol	175	346	26.7
Toluene	23	73.4	1.48
Turpentine, oil of	16	60.8	1.33
		Boiling Point	13.9

PROPERTIES OF COMMERCIAL SULPHUR

Insoluble in water.

Insoluble in most acids.

Tensile strength, 200 lbs. per sq. in. [approx.].

Heat conductivity, low: $\frac{1}{2}$ that of cork, $\frac{1}{4}$ that of ice.

Electrical conductivity lower than that of practically any other solid substance.

Melting point, depending on conditions, 110.2°–119.25° C. [230.4–246.7° F.].

Ignition temperature, 248° C. [478° F.].

Boiling point, 444.6° C. [832.3° F.].

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Taking the value of sand as $1 per cubic yard and of sulphur as $20 per ton, the price of the materials per cubic yard will be about $18. It may be possible to decrease appreciably the amount of sulphur necessary and hence the cost by imbedding larger pieces of crushed rock or some such substance in the mass. Tests of the material in sea water are being made, but it is too early to give results. It is apparently standing up well to date.

Pipes cast of this sulphur-sand mixture show no deterioration after one year in 5 per cent hydrochloric or 5 per cent sulphuric acid. The ordinary organic acids have no effect on such a mixture. The following extract is pertinent in this connection:

The Use of Sulphur and Sand in Sewer Pipe Joints [6]

In constructing a main line 36-in. sewer for the conveyance of acid waste for a pulp mill in Quebec the question arose as to what material should be used in pouring the joints. Cement was out of the question on account of the deteriorating effect acid would have upon it. A number of mills were corresponded with upon the subject, but no very satisfactory method was recommended.

Ultimately the use of sulphur and sand was suggested by the engineering department. Lead wool was considered but rejected upon the ground that the cost was high. On the other hand, sand was available on the ground from excavations and sulphur could be purchased at the dockside in Three Rivers.

The method used was as follows:

An ordinary iron boiling cauldron over an open wood fire was used for heating the sulphur and sand. The proportions were one to one. The whole was heated until the sulphur melted and a semi-liquid mass formed. Three pipes were placed vertically in the trench and by means of a galvanized conductor pipe bent at one end to fit into the flange of the pipe the mixture was poured from a ladle on the top of the trench directly into the joint. The joints of each section of the three pipes in the trench were then poured in the ordinary manner with the use of a runner.

The insides of the joints were pointed with wet clay. The joints cast and became solidified in about one hour after pouring. The length of time for solidification of course depended upon the coldness of the weather.

The joints so far have been all that could be desired, having

[6] *Pulp and Paper Magazine*, vol. 17, 1920, p. 998.

neither blowholes nor cracks. The solidified sulphur and sand is extremely hard and the only impression made on it with a large knife was to scrape fine particles away. In appearance it is almost metallic.

One possible tonnage use for sulphur which has been arousing a great deal of interest in the last two years is its application as a fertilizer. There are two methods of application which have received attention from experiment stations. During the war, when sulphuric acid was needed for munition manufacture, Lipman, of the New Jersey Experiment Station, showed that if sulphur is composted with ground raw phosphate rock the phosphate is rendered available within a reasonably short time. Bacteria in the soil oxidize the sulphur to sulphuric acid, which acts on the raw phosphate to give available plant food. It is thus possible to make available as high a percentage of phosphoric acid as is found in commercial acid phosphate. The work has been confirmed by other experiment stations and would undoubtedly have been of great importance if the shortage of sulphuric acid had continued. Lipman has since improved the procedure by isolating and growing pure cultures of the most active sulphur oxidizing bacteria and has prepared sulphur inoculated with these. Such a product is put on the market under the name "Bac-Sul" and it is understood that the Union Sulphur Co. is interested in its sale. Although we believe that a product of this kind will do all that is claimed for it, it is doubtful whether it means any immediate tonnage outlet for sulphur. Competent agricultural authorities advise that it is nearly impossible to get the American farmer to do composting and at best the introduction of any new type of fertilizer is a slow and tedious process. The other use of sulphur as a fertilizer consists in its direct application to the soil. The Oregon Agricultural College Experiment Station has shown very conclusively that certain soils in southern Oregon are immensely benefited in this way, so that the alfalfa crops have been greatly increased. Several of the other state experiment stations have reported the same experience for certain types of soils. In fact, results obtained by the use of sulphur as a fertilizer have in some cases been so remarkable as seriously to raise the question whether some of the standard theories on fertilizers will not have to be revised. Nearly all the experimental work through which phosphate has been given its high place as a fertilizer has been done with an acid phosphate

containing considerable quantities of sulphates. Similarly, in experiments with potassium and ammonium fertilizers, the sulphates have often been used. Any change in growth or yield has been ascribed to the phosphates, the potassium or the nitrogen. The question now arises as to how much of this change in plant growth was due to the sulphur entirely apart from the other fertilizing constituents.

Correspondence with virtually all the experiment stations in the United States on the subject of sulphur as a fertilizer has elicited opinions which virtually all boil down to the following: Very many of our soils either contain enough sulphur for plant requirements or receive sufficient in the rainfall and other water. There are also very many soils on which sulphur would undoubtedly prove to be an advantageous fertilizer either because of a deficiency in sulphur or because sulphur during its oxidation would make available from the soil other needed plant foods. Work is either under way or in project in almost every experiment station in the country to obtain more knowledge on this subject, especially to find out what soils in each particular state have need of sulphur. It is probable that in time this may mean a tonnage market for sulphur, but when it is considered that there is today definite proof that the farmers of the country as a whole could use to their own profit at least ten times as much fertilizer as they do it will be realized that the building up of a tonnage use of any new fertilizer promises nothing large in the near future.

The greatest problem of the American sulphur industry at the present time is to obtain immediately available new tonnage outlets for sulphur. The solution of this problem would mean a continued prosperity to the sulphur industry and a continuance of low-priced sulphur for the greater chemical industry.

MELLON INSTITUTE OF INDUSTRIAL RESEARCH,
PITTSBURGH, PA.

DISCUSSION

THE PRESIDENT: Gentlemen, you have heard the paper. It is now open for discussion.

DR. WEIDLEIN: There are some interesting photographs there of the Texas Gulf Sulphur plant, also those charts might be of interest since you are going over to visit the Union Sulphur plant.

I might say there has been a little different method used in

the development of the Texas Gulf Sulphur Company's plants than in other plants. It has been handled entirely by mining engineers, and they are employing, to a large extent, the experience of the mining profession.

DR. MOORE: Mr. President, I am very much interested in Doctor Bacon's paper, for this reason, that we have seen certain fermentation experiments with liquor containing sulphur. The most remarkable effect that has come to our attention is that even though we get the purest yeast that we are able to obtain, the sulphur compounds cause a growth of a certain bacteria which accumulates on top of the fermentation tanks in enormous quantities, and these bacteria developed with such rapidity in these sulphur solutions that, even though you started with as pure a yeast as it was possible to obtain, the growth is so remarkable that it practically cuts down your alcoholic fermentation almost completely, the growth of these bacteria being so great that you get entirely different fermentation than you do from a sugar solution without the presence of the sulphur compound.

What these bacteria are, we have not yet developed, but we know it is due to the presence of the sulphur compound, because we have never seen it in any other fermentation we have ever conducted. It is all due to the sulphur compound. The whole top of the tank is covered with a red bacteria of some nature. I do not know what it is, but it is due simply to the sulphur compound.

THE PRESIDENT: That is certainly a very interesting point. Have you made any attempt to remove the sulphur compound before starting fermentation?

DOCTOR MOORE: Well, the liquor is a digester liquor from the sulphite process, and the removal of the sulphur compounds would seem beyond reach of any immediate solution.

DOCTOR CHUTE: Mr. President, the fermentation of sulphite waste liquor is not, by any means, new. It has been carried on in a commercial way, both in this country and in foreign countries, for many years, and this is the first report we have ever had of any bacterial action of that kind, and it is quite possible there are some peculiar conditions under the circumstances in which this fermentation is made, and I hardly think that you can say that it is a bacteria which is developed from the sulphur, itself, seemingly with no parentage, as, if it has never been found on any other substance, the question is, how did it arise, because sulphite

waste liquor is not anything that has been produced in the past or by nature, so that if it develops bacteria automatically within two years, it is a rather strange thing and it is more strange that other people have not discovered any bacteria from the sulphite waste liquor. And it is very interesting to know what the bacteria were, and I think it is worthy of considerable further study.

DR. LANGMUIR: I just want to call Doctor Moore's attention to the fact that in Germany, during the war, when they wanted to produce glycerin instead of alcohol by fermentation of liquor, they added directly to the liquor sodium sulphite, and the fermentation then went in the direction rather of glycerin instead of alcohol.

THE PRESIDENT: It seems to me now it is up to somebody to find something to put in the glycerin so as to reverse the reaction. (Laughter.)

CONSERVATION OF HEAT IN POWER AND HEATING SYSTEMS [1]

By EDWARD R. WEIDLEIN

Read at the New Orleans Meeting, December 6, 1920

There are two distinct methods of conducting scientific research for industry. Each of them has its advantages and, generally speaking, both are followed in investigational practice. The first is the more obvious. It consists in taking problems which are quite familiar and attacking them with the powerful weapon which science has placed in the hands of its trained workers. This method is capable of very wide application and has afforded most valuable results.

The second method is not nearly so obviously useful, but the history of scientific discovery reveals that it is extremely powerful. It consists in beginning not with a definite problem, but with the systematic application of the different branches of science to the study of a material of economic value, for the purpose of gaining as complete knowledge as possible of the nature and properties of the material. At first sight this procedure may appear to business men to be very indirect, but the experience of some of our most enterprising industrialists and associations of manufacturers shows

[1] The data presented in this report represent part of the results obtained during the course of an investigation conducted for the Magnesia Association of America by the Mellon Institute of Industrial Research of the University of Pittsburgh. The object of the investigation is to determine the true facts regarding the value of "85 percent magnesia" as a heat-insulating material, and therefore the data are confined to this particular covering, and no effort has been made or will be made to furnish comparisons with other heat-insulating materials.

The researches carried out at the Institute under the supervision of the author have been conducted by the following Industrial Fellows: G. F. Gray (1917), Glen D. Bagley (1918), M. S. Mason (1919), T. S. Taylor (1920), and R. H. Heilman (1917–1920), the present incumbent.

The author wishes to express here his appreciation of the accomplishments of these Fellows and his gratefulness to W. L. Steffens, of the Philip Carey Co., Cincinnati, Ohio, and to P. Nicholls, of the Franklin Manufacturing Co., Franklin, Pa., for their constantly helpful co-operation during the progress of the investigations.

that in the long run it is more profitable than the obvious and direct method.

If it is conceded that the indirect method of approach is often the better, it must be borne in mind that it is usually the slower. This has been the case in the Mellon Institute's elaborate study of the characteristics of "85 per cent magnesia" as a non-heat-conducting covering for power and heating systems.

The industrial applications of insulating materials may be divided into three main classes—viz.: (1) Boiler plants, steam pipes, and heated surfaces of all descriptions; (2) refrigeration plants and cold storage; and (3) furnace settings. This paper will be confined to a consideration of the conditions encountered in the first-mentioned class, for all the data which have been obtained so far relate to the conservation of heat losses from pipes and boilers.

Fuel Economy Imperative

Heat insulation in all its varied aspects has a great future, since it is of recognized value in reducing working expenses, and specifically it is of very material aid in effecting fuel economy. It is recognized generally that the losses from bare pipes and boilers are considerable, but the real magnitude of these losses is little appreciated. The fact that the loss from 1,000 square feet of exposed surface at 100 lb. per square inch steam pressure represents over 300 tons of coal annually is a sufficient justification for the serious consideration of the subject.

The need for economy is becoming more imperative since the prospect for low-priced fuel in the immediate future does not seem to be very encouraging. Accordingly, there have been introduced improved methods of combustion, resulting in the operation of boilers at higher steam pressures and a general advance in boiler-room efficiency. However, the improved steam production is nullified to a large extent unless improvements are also made in the steam conveyances. Higher boiler pressures necessarily imply higher steam temperatures, and higher temperatures inevitably call for reconsideration of the whole question of insulation. The proper amount of non-heat-conducting material which should be applied to any heated surface will be that at which the cost of an increment of the covering will just balance the savings which will be accomplished by the increment.

Good Insulating Materials

A good heat-insulating material should have low heat conductivity; low specific heat, it being necessary that as little heat as possible should be absorbed by it; low specific gravity, in order to avoid the addition of undue weight and the introduction of undesirable strains in the piping systems; and sufficient mechanical strength to withstand vibration and accidental knocks. Moreover, it should be capable of withstanding the action of water and, preferably, also acids; it should be one which does not crack with alternate heating and cooling and with alternate wetting and drying; it should not disintegrate or decompose at the temperature to which it must be exposed; it must have no corrosive action on the surface to which it is applied; and it must be non-flammable.

Air is a poor conductor of heat. The transmission of heat through air is effected not in a considerable degree by conduction, as in the case of metals, but partly by radiation and largely by convection or by the currents set up by the difference in specific gravity of hot and cold air. This explains, therefore, why a good non-conductor of heat is generally found to be a porous material, or one which has entrapped pockets of air throughout its substance. For the highest insulating efficiency, it should have a uniformly honeycombed structure, and these pockets of air should be sufficiently small to prevent convection currents being set up in them.

The value of "85 per cent magnesia" as a non-heat-conducting material is increased greatly by the interlacing and felting together of the crystals to produce a block of magnesia containing 90 per cent of voids, which take the form of exceedingly small air pockets.

The name "85 per cent magnesia" denotes the fact that the coverings contain 85 per cent of basic magnesium carbonate, which is usually expressed by the following formula:

$$4MgCO_3.Mg(OH)_2.5H_2O.$$

The remaining 15 per cent is asbestos, which is introduced as a binder to insure the requisite structural strength and durability. The flow sheet shown in Fig. 1 illustrates the method of manufacturing this product.

Pennsylvanian dolomite rocks contain about 43 per cent of magnesium carbonate. The basic carbonate is separated in a pure form by a chemical process and is mixed with 10 to 15 per cent of asbestos fiber, after which the standard shapes and sizes are

formed by a molding process. After the drying process, which requires five or six days, the rough-molded sections are planed to true dimensions. The heat insulation value is due largely to the mass of minute air cells formed by the interlocking walls of the crystals. This is also the reason for the extreme lightness of the

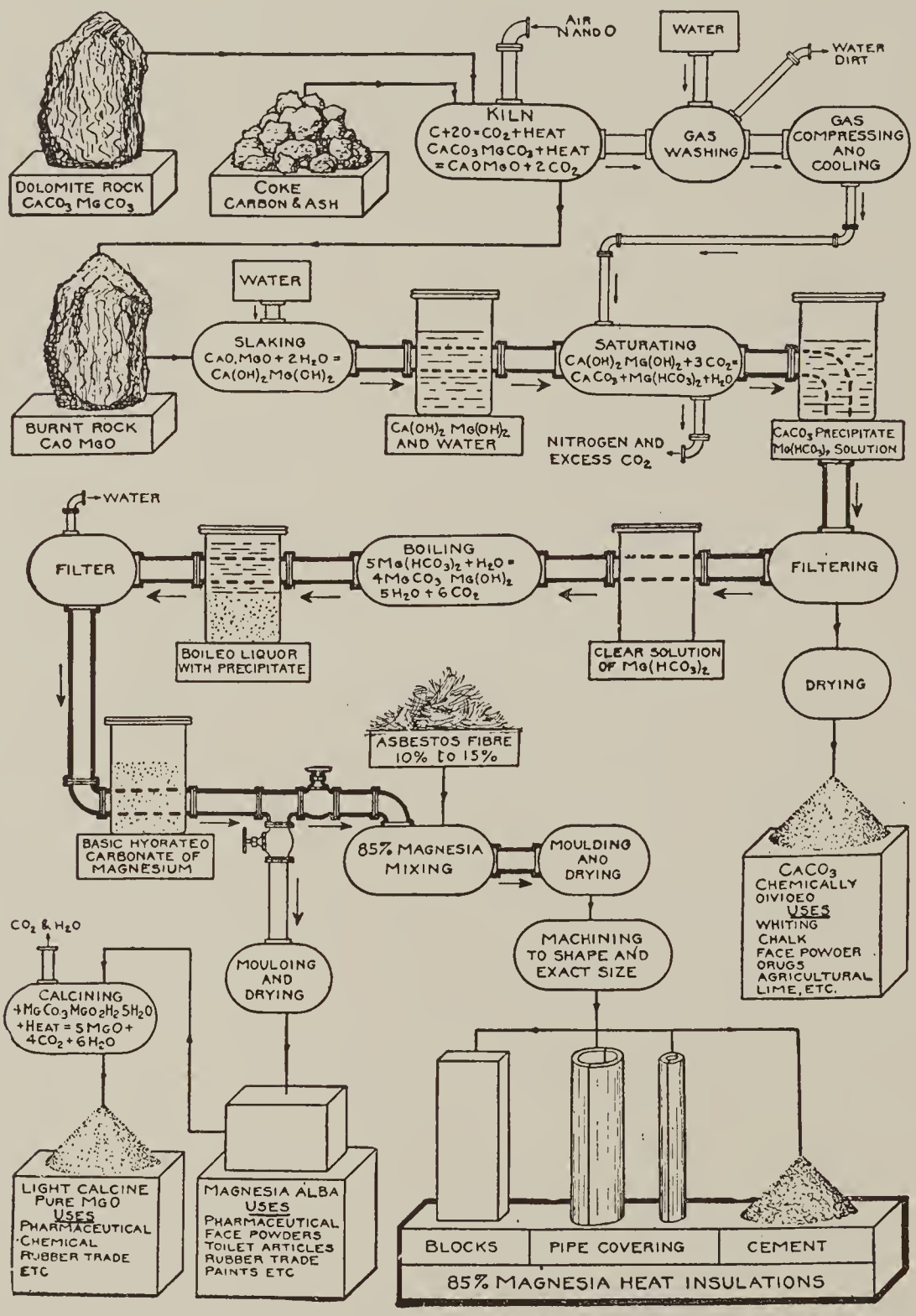


FIG. 1. Flow Sheet Showing the Manufacture of "85 Per Cent Magnesia"

product and for the ease with which it will absorb nearly three times its own weight of water. The Philip Carey Co., Cincinnati, Ohio; the Ehret Magnesia Manufacturing Co., Valley Forge, Pa.; the Franklin Manufacturing Co., Franklin, Pa., and the Keasbey

& Mattison Co., Ambler, Pa., have supported this investigation through the Magnesia Association of America and they represent a total invested capital of $16,500,000, which indicates the magnitude of this branch of chemical industry.

In a study of the conservation of heat losses, the first important fact to be considered is the actual value of the losses from bare surfaces. It is often considered that the loss from any bare surface is 3 B.t.u. per square foot per hour per deg. F. temperature difference between the surface and the surrounding air. While this value is correct for some special cases, it is by no means generally so.

Heat Losses from Bare and Covered Pipe

The full curves given in Fig. 2 [2] show heat losses from bare pipes, as predicted from Peclet's formula, and the dotted curve and

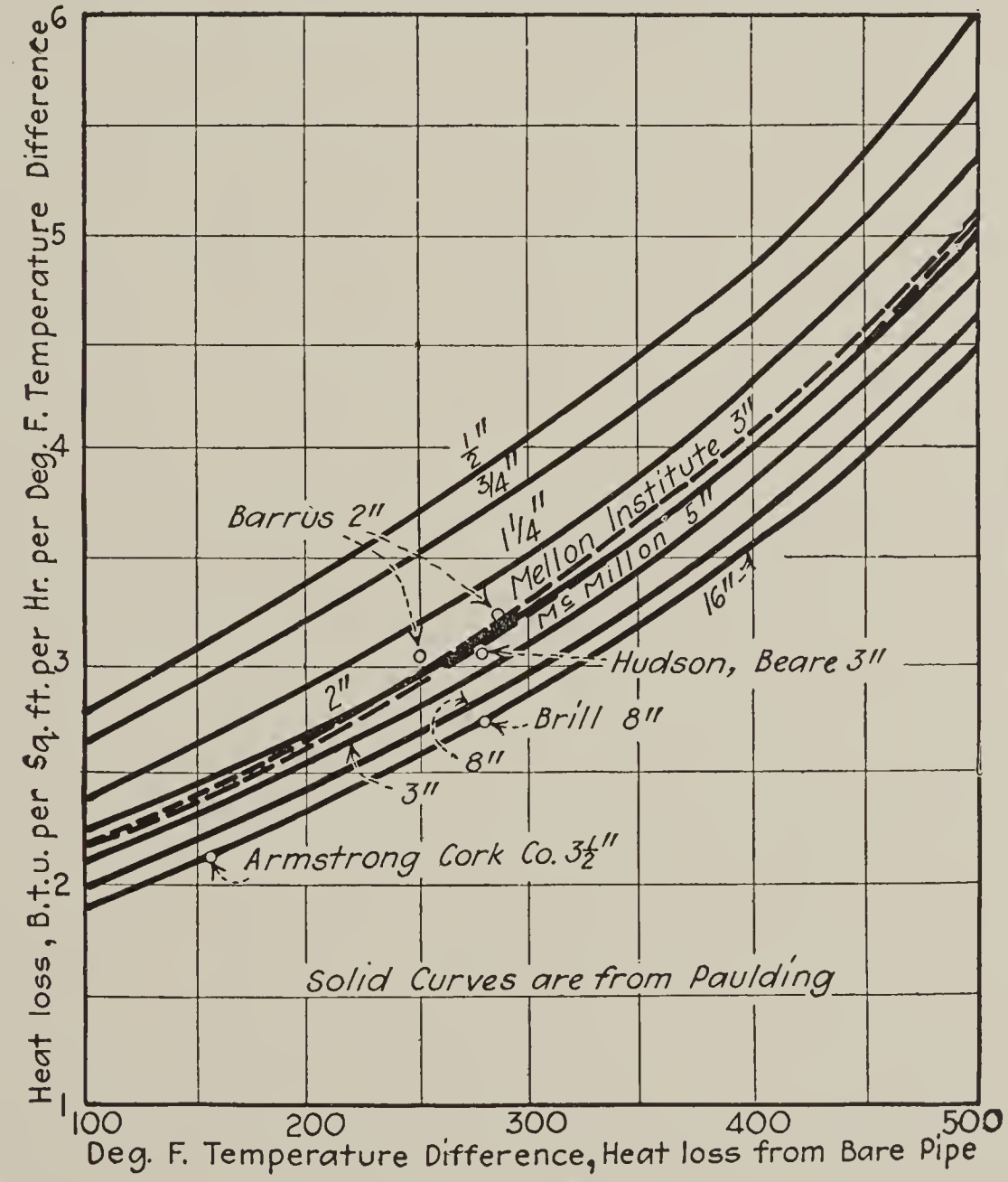


Fig. 2. Heat Losses from Bare Pipe

[2] See Bagley, *Trans. Am. Soc. Mech. Eng.*, vol. 40 (1918), pp. 667–94. Bagley presents detailed information regarding methods of tests and results.

points indicate the experimental results obtained by various investigators. The Peclet values agree closely with the experimental findings and can be used safely. They show that the constant may vary 50 per cent below 3 B.t.u. per square foot per hour per deg. F. to values far above it. At 500 deg. F. temperature difference, which is often attained with superheated steam, the constant increases to double this value for the smallest size pipe. In some chemical plants steam is used at temperatures of 1,100 deg. F. The importance of using very thick insulation at these temperatures is easily judged from the rate at which the loss increases at 500 deg. F.

The next important point in a consideration of the conservation of heat is the value of the loss after the pipes are insulated. The electrical apparatus used in securing the experimental data is designed to test the material under conditions corresponding to actual practice. Tests have been carried out on five different makes of magnesia coverings in 1-inch, 2-inch and 3-inch thicknesses. The results of the tests are given in Fig. 3. The contrast between the losses from a bare pipe and the losses through the various thicknesses of coverings is very striking. The efficiency increases with the temperature, for the loss from bare pipe increases much more rapidly in proportion than the loss from covered pipe.

Depreciation Rate Low

Pipe coverings may be subjected to wetting from leakage, floods, careless use of the hose, etc. Then, too, the necessity of removing and replacing the covering may arise. These questions, together with many others with regard to the permanency of the insulating qualities, rendered it necessary to conduct a careful investigation in this field, not only of new coverings but of coverings which had been in service for a number of years.

Tests were made to determine the effect of alternately wetting and drying coverings in relation to the change in heat conductivity, the change in mechanical structure and other physico-chemical properties, and the possibility of removing and reapplying coverings which had been wetted.

The following routine test was made:

1. Inspect, photograph, weigh, measure and apply the sections of pipe covering.

2. Heat the covering forty-eight hours at a pipe temperature slightly above 212 deg. F.

3. Measure the heat conductivity of the covering up to 400 deg. F. (temperature difference from pipe to air).

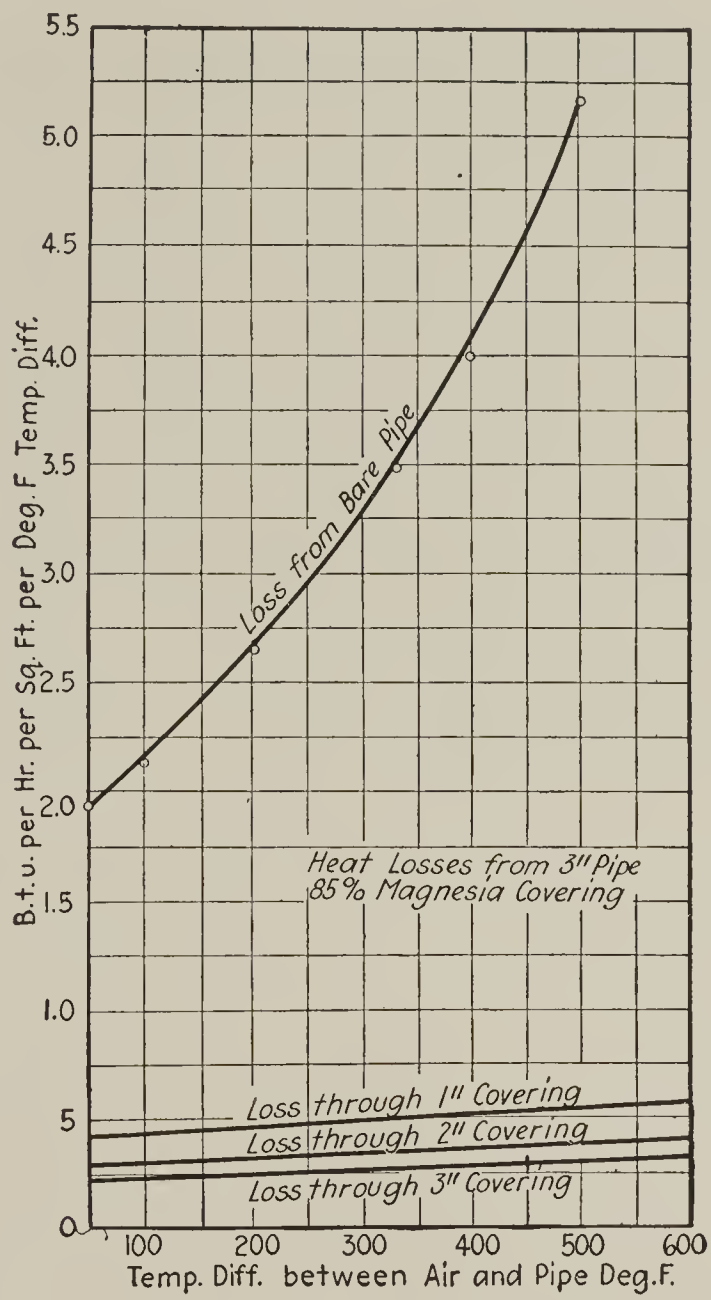


FIG. 3. Heat Losses Through "85 Per Cent Magnesia" Coverings on 3-Inch Pipe

4. Immerse the covering in water for thirty minutes, then dry the covering on the pipe at a temperature difference not exceeding 400 deg. F. Wet the covering four times, drying it after each wetting. Conduct the fourth drying at pipe temperatures of 212 and 250 deg. F.

5. Measure the heat conductivity up to 400 deg. F. (temperature difference from pipe to air).

6. Observe and record the physical effects of the test upon each covering.

The magnesia coverings were removed successfully after each drying, then weighed, soaked, weighed again and reapplied four

times. Fig. 4 is a photograph taken of the covering before and after the wetting and drying tests. The heat conductivity is shown in

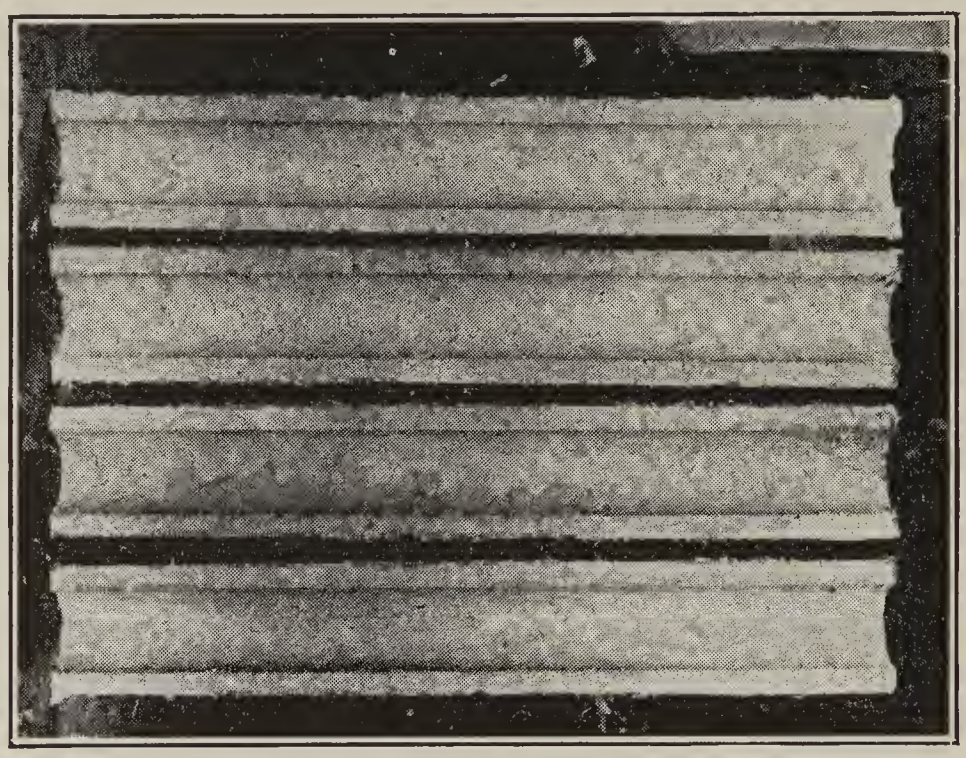


FIG. 4. Condition of "85 Per Cent Magnesia" Covering Before (Top) and After (Bottom) Wetting and Drying Tests

Fig. 5, before and after wetting. The insulation value is increased, but in all cases the average shows the same conductivity before and after wetting and drying. The coverings were as strong after the test as before and could be reapplied readily, giving further evidence that they had not deteriorated; "85 per cent magnesia" has a crushing strength of about 100 lb. per cubic inch, which is

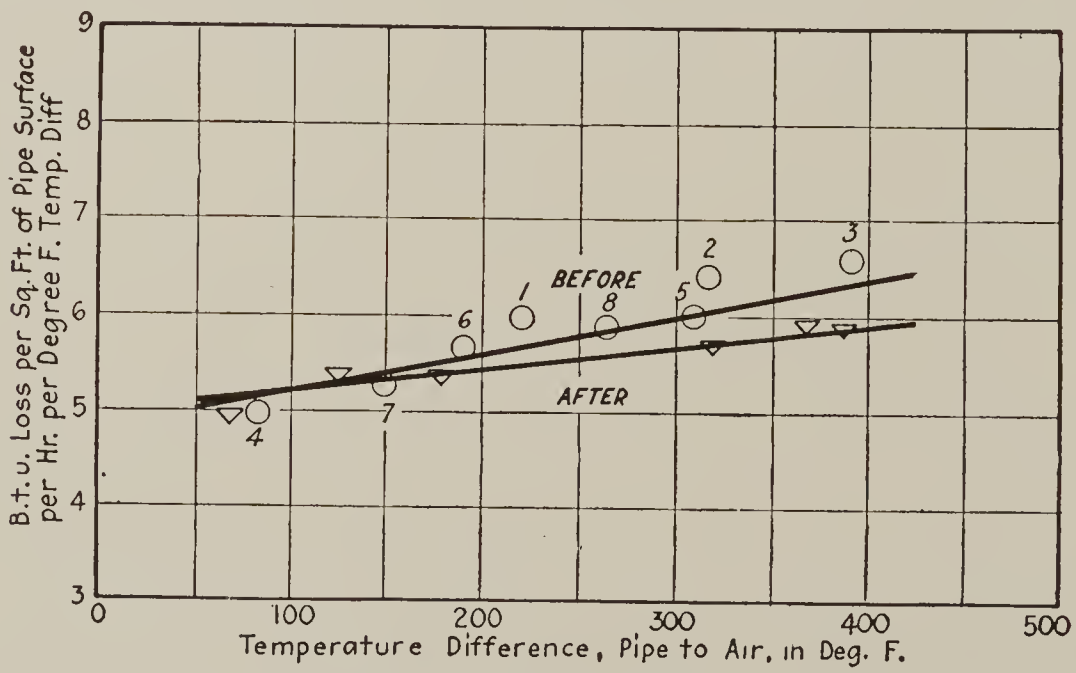


FIG. 5. Comparison of "85 Per Cent Magnesia" Covering Before and After Wetting and Drying Tests

more than sufficient to withstand any of the ordinary strains or proper conditions under which it should be used.

Tests were made on several old magnesia coverings. Fig. 6 shows the conductivity of a 1-inch thick covering which had been in service for eight years in the Armour Glue Works in Chicago. The insulation value was slightly higher than the average of the new 1-inch coverings tested, showing that no deterioration in service had taken place. In the Niagara Power Station, in Buffalo, N. Y., "85 per cent magnesia" has been in service from sixteen to twenty years. A section and blocks were tested and found to have increased in insulation value approximately 3 per cent. Several sections were obtained which had been saturated with oil.

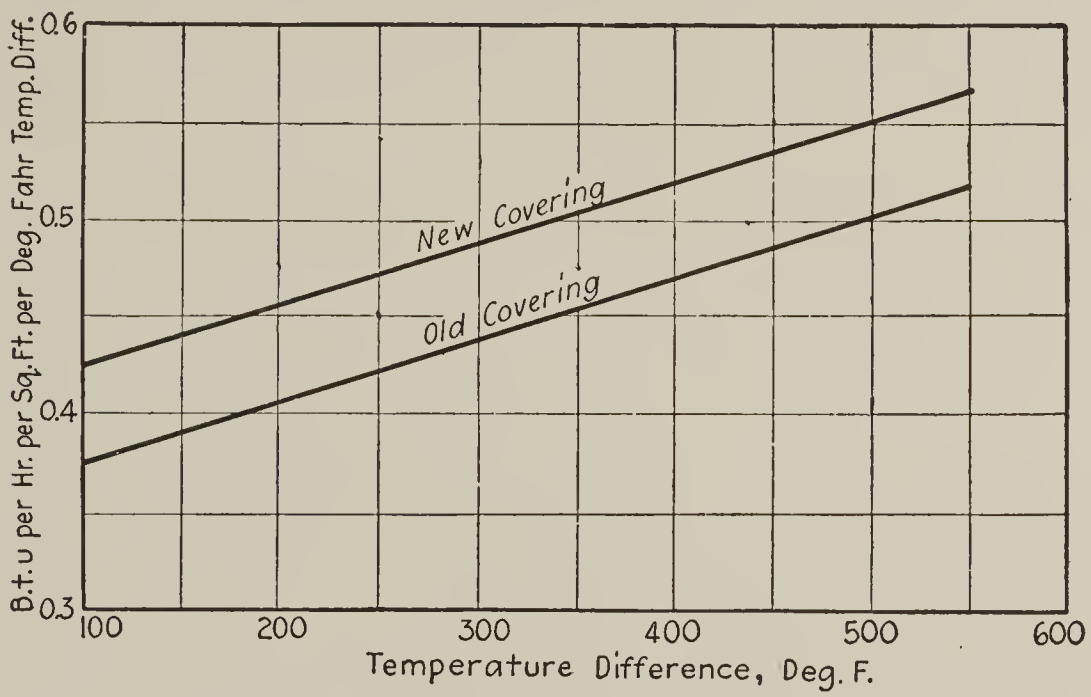


FIG. 6. Comparison Between Old and New Coverings

Tests on these showed much lower insulation values than new coverings. The damage was permanent and showed that care should be taken to protect coverings from oil while in service. Figs. 7 and 8 illustrate the conditions to which coverings are sometimes subjected and the value of having a good permanent covering.

Upon inspecting various installations of insulated steam pipes, it has frequently been noted that the pipe has suffered considerable deterioration. This rusting of the steam pipe has in many cases been explained as being due to the action of the particular covering on the pipe, and not simply to oxidation on account of the pipe and coverings being frequently wetted.

The results of tests conducted in order to determine the probable influence of various factors on the rusting of insulated steam pipes

indicate that the pipe coverings in general, especially if alkaline in composition, do not of themselves promote rusting on steam pipes

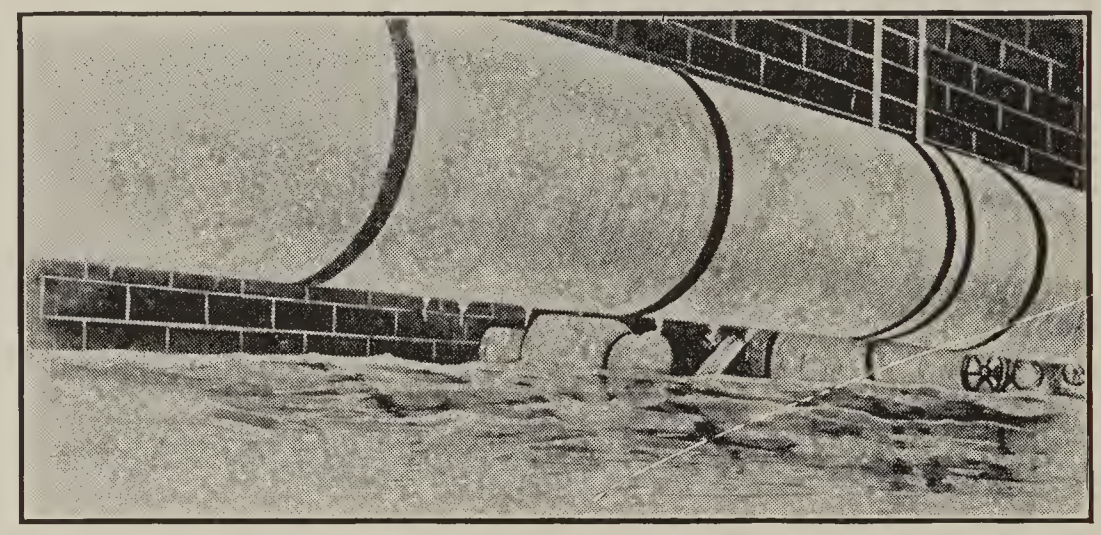


FIG. 7. This Pipe, Covered with "85 Per Cent Magnesia," was Submerged for Three Weeks by Flood Water Without Damage

when they become wet. In fact, they really act as a protecting coating, since the oxygen does not get into intimate contact with the surface of the pipe. However, an electric current flowing through the covering may either promote rusting of the pipe or it

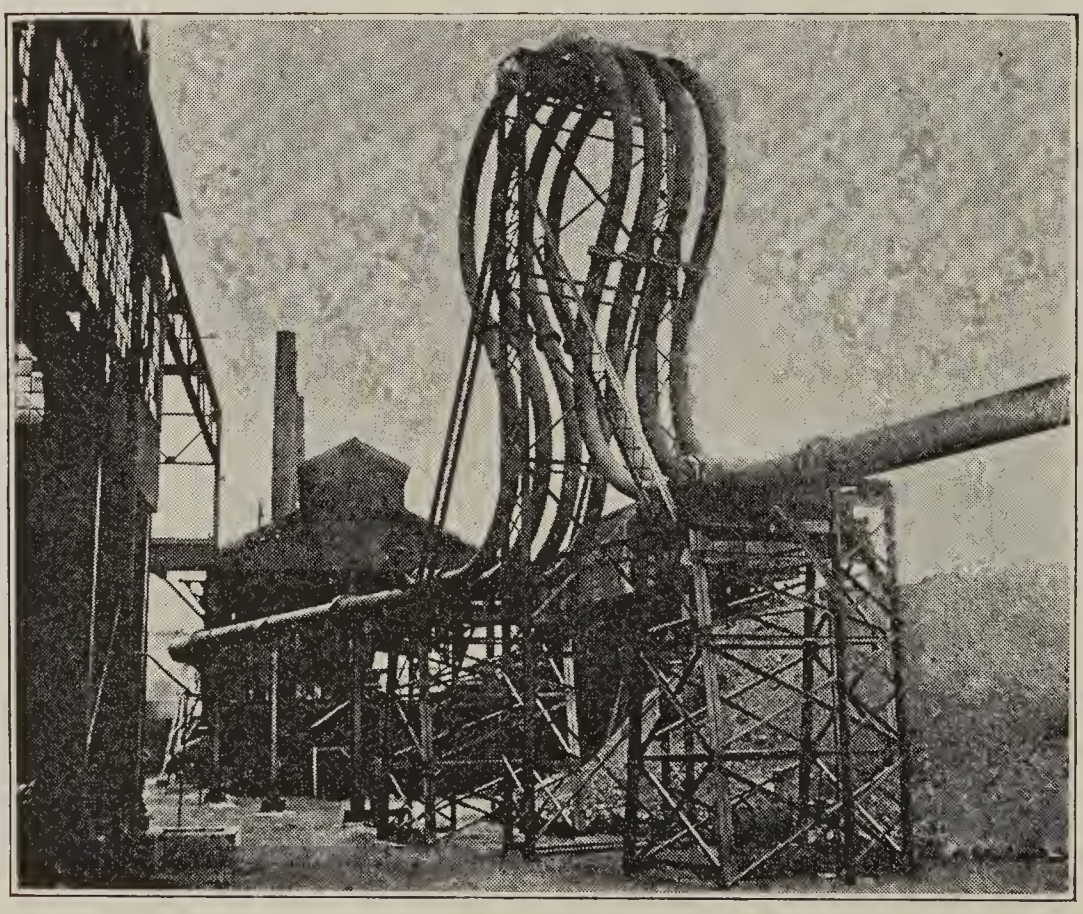


FIG. 8. Expansion Joint in 750-Foot 22-Inch Pipe Line Carrying Steam at 150 Lb. "85 Per Cent Magnesia" Covering on this Line Saves 1,300 Tons of Coal Annually

may retard corrosion, depending upon the direction in which it is flowing. When the current flows from the pipe to the outside of the covering, this causes the oxygen separated by electrolysis to be liberated at the pipe, thus promoting the rusting of the pipe. The greater the current flowing the greater will be the rusting effect, so that if sufficient current were flowing a covered pipe might rust as much as the uncovered. When the current flows from the outside of the covering to the pipe, hydrogen formed by electrolysis is liberated on the pipe, which tends to retard any rusting of the pipe. The action of the electric current would be the same on an uncovered pipe, and the quantity of rust formed no doubt would be in the same proportion as was found in the cases of the exposed and covered pipes.

As the tendency in industry is to use higher temperatures, tests have just recently been completed at a temperature of 800 deg. F. The pipe was maintained at a temperature of 800 deg. F. for a period

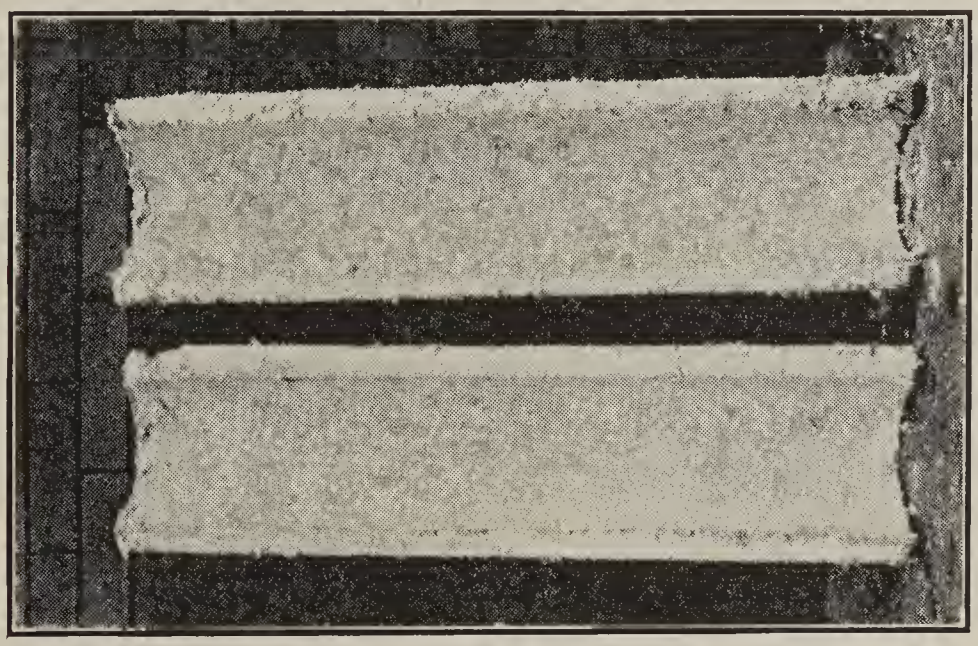


FIG. 9. Section in Use Four Years at Temperatures from 650 to 800 Degrees F.

of two months. The covering showed the average conductivity value, and after the test was not only successfully removed from the pipe but was in such a condition that it could have been successfully reapplied.

This finding agrees with the results obtained under actual working conditions in the plant of the Buffalo General Electric Co., Buffalo, N. Y. This company has in service 10-inch, 6-inch and 3-inch steam lines which carry steam 75 per cent of the time at a temperature from 650 to 700 deg. F. with a peak temperature of 800 deg. F.

The pipes have been covered with "85 per cent magnesia" for four years, and Fig. 9 shows in perfect condition a section of the covering removed from the 6-inch vertical steam line.

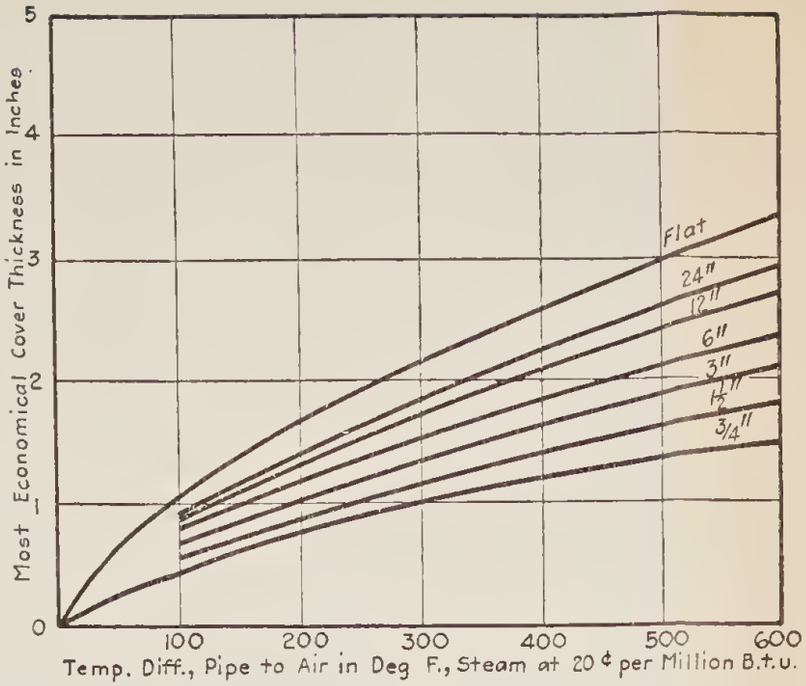
The Economical Amount of Insulation

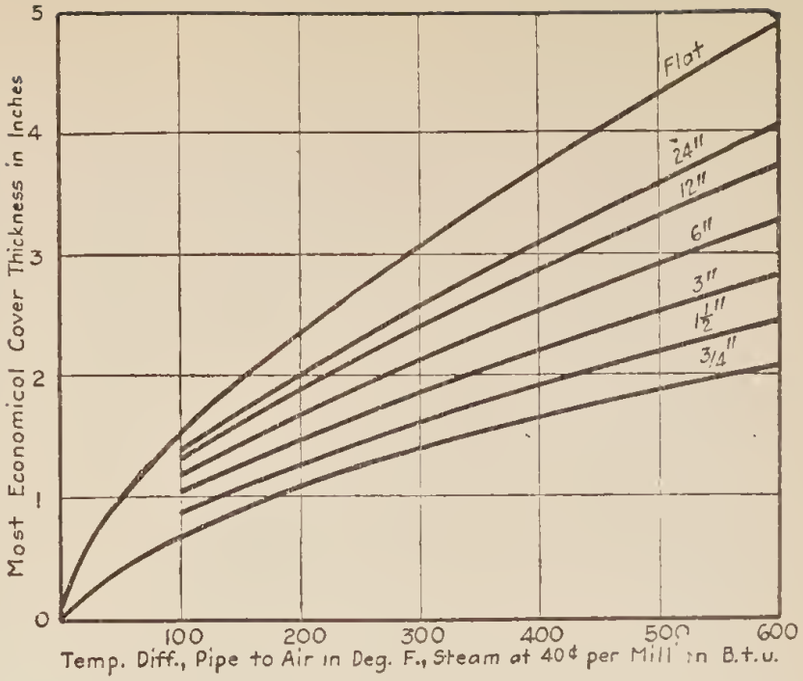
A careful study of the technical and theoretical sides of any problem is essential in order to determine the economic value of the process or product, and so with "85 per cent magnesia" covering the result desired is the maximum net saving of money for any given condition. If the covering cost were nothing, the proper thickness would be limited only by the requirements of space available, for each increased thickness would result in some slight increased saving in heat. In a practical case where the covering has a definite cost, a point is reached where the increased cost of the covering will be greater than the additional saving in heat effected. It is this point in which the user of coverings is most interested, for it defines the maximum net saving to be accomplished.

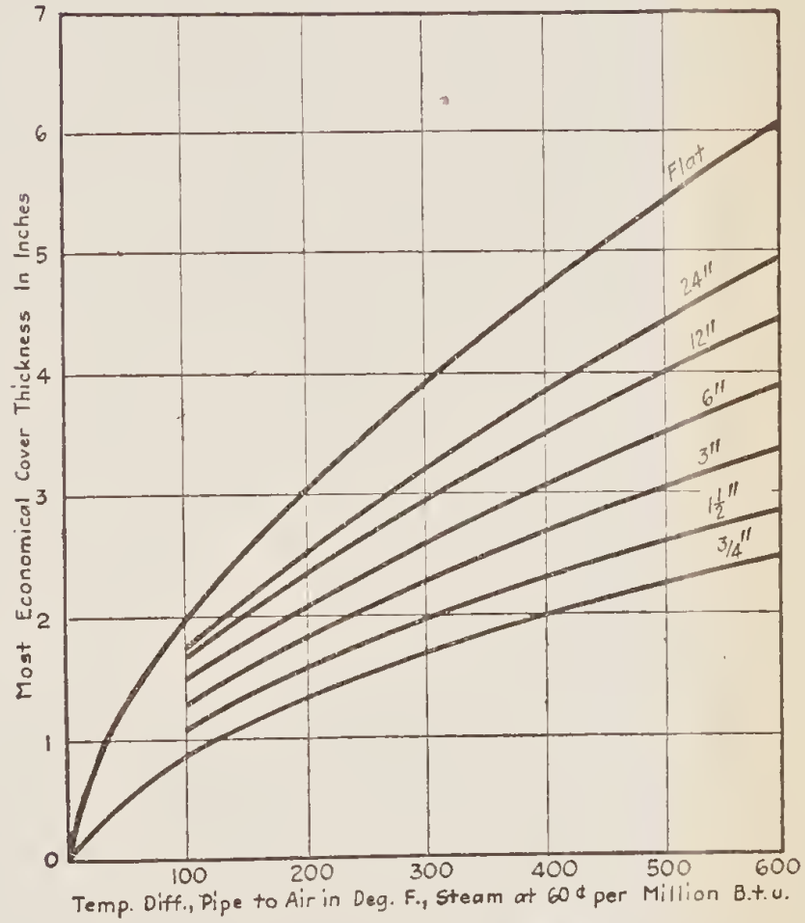
One important factor to take into consideration is the fact that prices of coverings vary with the thickness. For flat surfaces the price is directly proportional to the thickness, starting at 30c. per square foot for coverings 1 inch thick. The difficulties encountered in the manufacture of molded coverings for pipes result in an increased cost per square foot for a 1-inch thickness, and the cost increases much more rapidly with the thickness than in the case of flat surfaces. More material is also required in molded coverings per square foot of pipe surface than in the same thickness in flat blocks, on account of the curvature of the surface.

The cost per square foot of surface covered can be determined for any thickness desired. From this cost the annual fixed charges due to the covering can be calculated. After considerable investigation, it has been determined that 20 per cent of the list price of the covering would be a fair allowance for the cost of application, and 13 per cent of the total cost as the annual charges (6 per cent interest, 5 per cent depreciation, and 2 per cent insurance and miscellaneous). This fixed charge has been calculated for seven different sizes of pipes and five different thicknesses, based on the manufacturers' list costs of coverings.

The other cost to be charged to the operating expenses of the covering is the value of the heat losses through the different thicknesses of coverings. The previous work done on measuring the loss







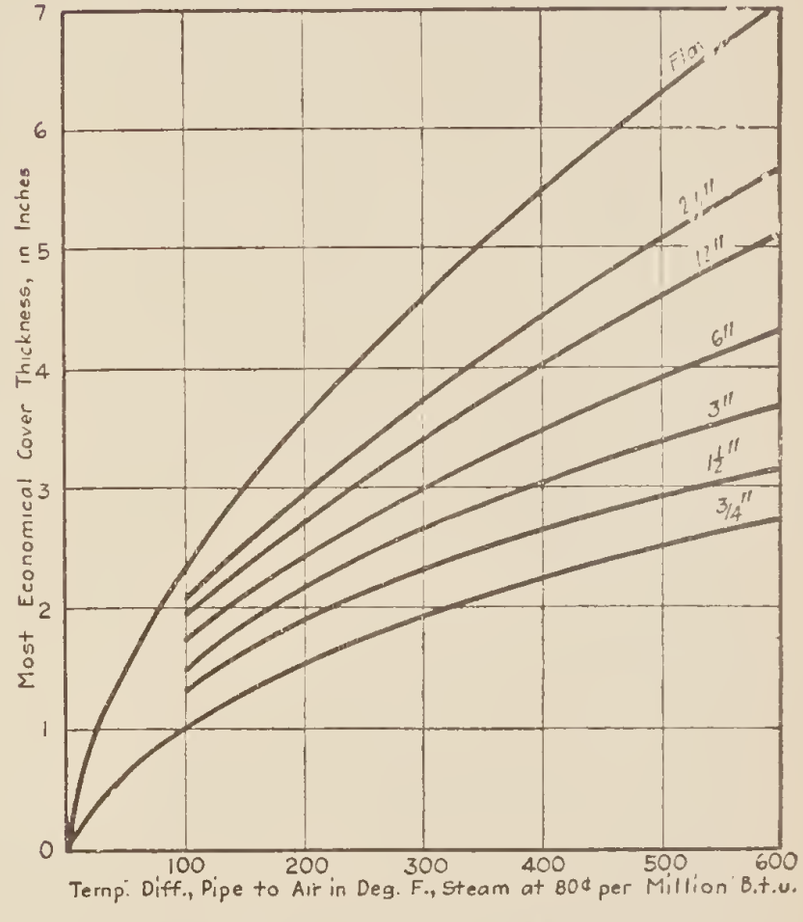


FIG. 10. Thickness of Covering for Maximum Net Saving with Steam at 20c., 40c., 60c. and 80c. per Million B.T.U.

through a large number of samples of magnesia furnished the necessary data for calculating the loss in heat units. After the heat loss was determined, it was necessary to convert the loss into dollars and cents. The assumptions used in making this conversion were that 1 pound of coal as burned will evaporate 7 pounds of water from and at 212 deg. F., and that each pound of steam contains 1,000 B.t.u. above the feed-water temperature. The value of the heat losses was calculated for seven sizes of pipes, five temperature differences between pipe and air, and four different costs of heat, both on the basis of a known cost per million B.t.u. and on a cost per ton of coal and the average conditions of steam generation given here. By making these calculations both ways, the results are applicable to plants where the steam costs are accurately known as well as to those where accurate records are not kept.

By combining the fixed costs and the heat losses per square foot per year, the total operating expenses were obtained. Once these are known, it is simply a matter of selecting that thickness which gives the minimum annual operating expense to obtain the proper covering to use. It is evident that the thickness which gives the minimum operating expesne also gives the maximum net saving, as the loss from bare pipe is a constant under given conditions and the net saving is the difference between the operating expenses and the loss from bare pipe. The curves in Fig. 10 are for use in plants where heat costs, steam temperatures, etc., are accurately known. They are applicable to all heated surfaces, since they are based on the temperature of the surface and the value of the heat in dollars per million B.t.u.

Amounts of Coal, Heat, and Money Saved by Installation

The savings accomplished by the use of the economic thickness of pipe covering is comparatively very great. The use of "85 per cent magnesia" of suitable thickness will result in a saving which will repay the original cost of the installation in less than a year in practically every case, and under constant operation at high temperatures where great thicknesses are called for the saving will often pay for the installation in as short a time as two months.

Table I shows the actual cost saving per month with $5 coal by the use of "85 per cent magnesia" pipe covering. Table II presents in greater detail the serious losses which are going on in many plants today—losses which are wholly preventable but which amount in the aggregate to many tons of coal yearly.

TABLE I.

MONTHLY SAVING, IN DOLLARS AND CENTS, BY THE USE OF "85 PER CENT MAGNESIA" PIPE COVERING.

Standard Thickness, Per 100 Lineal Feet of Steam-pipe.

Size of Pipe.	5 Lb. Steam Pressure.	10 Lb. Steam Pressure.	50 Lb. Steam Pressure.	100 Lb. Steam Pressure.	150 Lb. Steam Pressure.	200 Lb. Steam Pressure.	200 Lb. Steam Pressure, 100° Superheat.
½	$1.44	$1.58	$2.20	$3.28	$3.66	$4.11	$6.80
¾	1.72	1.89	2.87	3.70	4.26	4.89	8.03
1	2.11	2.30	3.56	4.80	5.35	6.04	10.00
1¼	2.52	2.74	4.22	5.52	6.50	7.25	12.20
1½	2.86	3.10	4.73	6.14	7.29	8.17	13.70
2	3.53	3.74	5.86	7.63	8.93	10.11	16.80
2½	4.25	4.39	6.95	9.07	10.55	11.90	19.90
3	5.00	5.33	8.30	10.90	12.60	14.30	23.82
3½	5.72	6.22	9.60	12.40	14.40	16.32	27.23
4	6.50	7.06	10.60	14.05	16.40	18.40	30.85
4½	7.30	7.69	11.80	15.35	17.92	20.25	34.00
5	7.97	8.64	13.16	17.20	20.00	22.72	38.00
6	9.36	10.15	15.60	20.38	23.82	26.88	44.90
7	10.90	11.70	18.38	23.68	27.60	30.80	52.00
8	12.26	13.22	20.40	26.60	31.20	34.90	58.55
9	13.80	14.70	22.70	29.00	34.52	38.61	64.80
10	15.08	16.33	25.00	32.70	38.40	43.08	72.40
100 sq. ft. 1¼-in. thick, flat surface	5.26	5.67	8.80	11.50	13.48	15.12	25.44

BOILER TEST CHECK ON LOSSES

In order that the results of the laboratory tests might be checked on a larger scale, several practical tests were made. The first and most important of these was a boiler test made at a mine in Bruceton, Pa. There were two boilers in the plant, of 80 and 60 hp., locomotive type. The total exposed surfaces on these boilers amounted to 675 square feet. The tests covered a period of twenty-four hours. Conditions of load, etc., were practically the same during both tests. During the first test, while the boilers were uncovered, 10,784 pounds of coal were burned to evaporate 58,000 pounds of water. In the second test, after the boilers had been covered with 2 inches of "85 per cent magnesia" blocks and plastic, 9,296 pounds of coal were burned to evaporate 59,500 pounds of water. The evaporation rate during the first test was 6.35 pounds

TABLE II.

COAL SAVED BY "85 PER CENT MAGNESIA" COVERING, 1-IN. THICK.

Steam Pressure.	Saturated 5 Lb.	Saturated 10 Lb.	Saturated 50 Lb.	Saturated 100 Lb.	Saturated 150 Lb.	Saturated 200 Lb.	200 Lb. Pressure with 100 Deg. Superheat.
Steam temp., deg. F.....	228	240	298	338	366	388	488
B.t.u. loss per hr., sq. ft. bare pipe.....	367	409	625	802	937	1,058	1,735
B.t.u. loss per hr., sq. ft. of pipe covered with "85 per cent magnesia".....	69	76	105	126	142	153	210
B.t.u. saved per sq. ft. by covering pipe with "85 per cent magnesia".....	298	333	510	676	795	905	1,525
Tons (2,240 lb.) coal saved per 10,000 sq. ft. per yr. of 8,760 hr. by pipe covered with "85 per cent magnesia"	1,190	1,330	2,080	2,700	3,180	3,620	5,650
Cars of coal saved per year, as above, at 40 tons per car..	30	36	52	68	80	90	140

of water from and at 212 deg. F. per pound of coal as fired, and during the second 7.55 pounds; 1,500 pounds more water were evaporated with 1,488 pounds less of coal burned. If calculated for an equal evaporation of water, the saving in coal would be 1,700 pounds per day. The calculated saving based on the laboratory experiments was between 1,400 and 1,500 pounds per day. This saving amounts to 15 per cent of the coal burned, due to covering the boiler alone, as the pipe lines were not included in the test.

NECESSITY FOR HEAT INSULATION LIKELY TO BE OVERLOOKED

The matter of insulating against heat losses has been accorded general attention in service power plants, large factory power plants and office buildings; but unfortunately, since it invariably receives final consideration in the construction of power and heating systems, it sometimes is regarded as a luxury—added only for the sake of appearance or neglected to save investment costs. The present tendency is to practice economy, and everyone realizes the importance of conserving the natural fuel supply, and yet the few finishing touches in the way of applying a good non-heat-conducting cover to protect such losses often are overlooked. It is one chemical product

that will continue to work independently of the human element of control, and for many years to come will continue to effect economies figured in the cold business way of dollars and cents.

MELLON INSTITUTE OF INDUSTRIAL RESEARCH,
UNIVERSITY OF PITTSBURGH,
PITTSBURGH, PA.

DISCUSSION

THE PRESIDENT: Mr. Weidlein's paper has impressed upon us probably more than ever the importance of protective coverings on boilers and steam pipes. We have all learned a great deal from it. The paper is now open for discussion. Does anybody wish to make any remarks?

DR. HOWARD: Mr. Chairman, I would like to ask Mr. Weidlein if his experiments extended to any other kind of pipe covering.

MR. WEIDLEIN: I explained that point in my paper, Doctor Howard. In the work at the Mellon Institute, as you will realize, we are very careful to make all the work unbiased from every standpoint; and while we have conducted experiments with other coverings, we have never even given the data to the Magnesia Association of America, and will not give it out, because, just as sure as we would, it would be used as a comparative test for advertising purposes.

DR. HOWARD: Have you ever made tests on hair felt for colder temperatures?

MR. WEIDLEIN: Yes; 85 per cent magnesia covering, as you will notice, is used for the higher steam temperatures. We have two types of coverings. Magnesia comes under what we call the high steam temperature coverings, and hair felt ordinarily comes under the low steam temperature coverings, for use in refrigeration purposes and so forth.

DR. HOWARD: I have found in some cases a combination of the two worked very well. An inch and a half of magnesia and then an inch of hair felt.

SECRETARY OLSEN: On the outside?

DR. HOWARD: Yes. For an outside line with roofing paper outside of that, and I have seen, in lines of that kind, in the neighborhood of Boston, snow lie on top of the steam pipe for two weeks before it melted off, outdoors.

DR. MOORE: Mr. Chairman, from a scientific point of view, though perhaps not from a practical point of view, I wish to state

that I noticed that the pipes that he mentioned here, the smallest pipes are ¾ inch in diameter. Now, we have reason to believe that the theory that increase of thickness gives increased insulation does not apply to very small pipes. In fact, if you will go down to pipes less than ¼ inch, there is a place where increase of thickness will increase your losses from a pipe, rather than decrease the losses from a pipe.

THE PRESIDENT: That is certainly a very interesting point.

MR. WEIDLEIN: That is true where you get below your one-inch pipe. That is the reason that all our data are calculated, as you will notice, on pipe sizes of one inch and up. Up to the present time there have not been enough data obtained on this particular point; and you will recall from the curve which I showed you of heat losses from bare pipes, that these heat losses were determined from one size of pipe, namely, a three-inch pipe. Up to the present time there is no formula for calculating the heat losses accurately from these data for the other size of pipes. Just now we are working along this line and hope to be able, within a reasonable length of time, to supply the necessary data with regard to heat losses from all sizes of bare pipe. The data presented in this paper have been obtained over a period of four years, and you will readily see that we have a good many years' work ahead of us in this field.

DR. BADGER: As a matter of theoretical interest, I want to point out that Mr. Weidlein's work, although it is a long distance from the work I have been doing on evaporators, checks out some of the work I have been doing, namely, that of our work on the relation between heat transmission and temperature drop, the work which I reported on in Montreal, that was done in our evaporators, especially. that as we increase the temperature difference between steam and water, we get a rapidly increasing coefficient of heat transmission. I notice that Mr. Weidlein, in a widely different kind of system, has gotten the same thing, that as the temperature difference between pipe and air increases, the coefficient increases. In other words, we cannot think of the heat transmission coefficient in any kind of system being constant, but we must remember that that is going to vary with the temperature difference, and it is going to vary very widely. We have always been accustomed, in the past, to think of the transmission coefficient as being a constant. It is not so, and this is simply another confirmation of that general principle, and shows not simply a little difference, but a very large difference, a difference

of 100 per cent in a difference of — as I remember Mr. Weidlein's figures, he shifts from 200 or 300° F. to 500° F. and increases the coefficient by 100 per cent.

In connection with what Dr. Moore said about small pipes, I remember what was said to me by one of the men of the Carnegie Institute, and he found that a coat of aluminum paint is a very good insulator for the moderate temperature pipes.

DOCTOR MOORE: I wish to bring out one other fact that is not germane to this discussion, namely, that at very high temperatures the heat loss of radiation, inasmuch as it follows the difference of the fourth powers of the absolute temperatures, may be more than the heat losses by convection. In such cases, an air insulation is a bad thing when you reach very high temperatures — none of the temperatures mentioned here, but when you get up, say, to 1500 or 2000° Centigrade, the losses through air due to radiation, owing to following the fourth powers, is greater than those losses through the material.

SECRETARY OLSEN: That is, you would use a solid material there?

DR. MOORE: I would use a solid material there.

THE PRESIDENT: Is there any further discussion, gentlemen?

DR. ZEISBERG: Apropos of Professor Badger's remarks in connection with the increase of the magnitude of the transmission coefficient, I would like to mention a paper published by Doctor Carl Hering, of Philadelphia, a few years ago, which seems to be unknown to a great many engineers. He conducted some experiments in heat transmission from flame to boiling water, and he discovered that, by operating the boiler surface next to the flame at a temperature around dull red heat, he got a perfectly enormous increase in heat. That fact does not seem to be generally known among the engineers who are quite familiar with heat transfer calculations.

THE SULPHURIC ACID PLANT FUME PROBLEM

By FRANK C. VILBRANDT and JAMES R. WITHROW

Read at the New Orleans Meeting, December 6, 1920

This paper emphasizes the importance of devising ways and means for conserving the sulphuric acid industry by helping it to eliminate its fume nuisance troubles which so frequently damage agricultural interests and antagonize urban ones. The paper also points out that the elimination of fume nuisance is all the more necessary because of the very fact of this acid industry's growing importance in chemical manufacture, in the pickling or cleaning of iron and steel before finishing such products as wire and tin plate, in the refining of petroleum products, and most important of all, because of the volume used, in the manufacture of superphosphate fertilizer for the development of agriculture. The importance of the sulphur-dioxide fume phase of the problem in connection with sulphuric acid manufacture is especially emphasized. The desirability of greater uniformity in fume nuisance legislation is pointed out. The need is also pointed out for adequate chemical means of detecting fume escape and the extent of atmospheric pollution, to help plants defend themselves against polluting the neighborhood atmosphere, as well as against losses in production. Current methods and suggested improvements, together with certain phases of investigational study in progress upon this problem supported by the Engineering Experiment Station of the Ohio State University, are briefly discussed. Satisfactory methods and standards are still uncertain matters. Serious co-operation in this matter with manufacturers by the American Institute of Chemical Engineers, and other available agencies, is urged.

The object of this paper is to arouse comment, suggestion and criticism calculated to bring out every point of view and all available assistance in the abating of the fume nuisance near sulphuric acid plants.

The operation of chemical industries, even if properly managed, is often attended by the emission into the surrounding atmosphere of fumes or odors of various kinds. In the case of the sulphuric acid

industry this emission of fumes is frequently the rule, though there are some plants remarkably free from objection. Now to prevent this frequent loss of gases from becoming a deserving basis for litigation is a question of vital interest to the industry. The growing importance of the sulphuric acid plant fume problem will probably force drastic legislation regulating the operation of these plants. Before any positive legislation is passed regarding the operation of such plants, it behooves the chemist and chemical engineer to anticipate such action and furnish proper and adequate methods for establishing the standard to be adopted. Regarding this latter point, the unreliability of some of the proposed methods of pollution evaluation will be developed later.

The importance of sulphuric acid manufacture to agriculture and the arts makes the public interested in conserving this industry. This fact, however, does not warrant the industry in maintaining a nuisance by its escaping fumes. In fact, the public will insist upon not being imposed upon and therefore as the population concentrates in our eastern and other manufacturing centers, the problem must be handled with candor and expedition. The acid maker must be a good citizen with his plant as well as otherwise. He cannot hope to rest long on his accomplishments like the western smelter manager, who once said that he had no more court troubles since he had been able to show that he had purchased the same fume poisoned horse or cow nearly two dozen times, and each time from a different farmer upon whose premises it was alleged to have died from smelter fumes, a familiar form of graft known in the west as "smoke-farming."

The opposition, which of late years has become almost universal in settled localities, is partly based on real ground of complaint and partly feigned for motives of self-interest. A good deal of it takes the form and spirit of blackmail, being instigated by the expectation of procuring tribute from the proprietors, who are frequently obliged to expend great sums on settling law suits brought to recover damages alleged to have been suffered on account of the fumes. However, the allegations on which such suits are based generally refer to growing crops and plants, which show evidence of damage.

The natural consequence of locating such plants too close to communities, or having communities grow up around them, is to create trouble in the neighborhood from parties rightfully, or un-

unscrupulously influenced by legal advice as to the danger of SO_2 and SO_3, or H_2SO_4, fumes and also from the effect they have on vegetation, as indicated by wilt markings and final destruction. The money entailed in fighting these cases being considerable, has caused more attention to be paid to the latter, than to the operation and management of the plants themselves in some cases.

Even when such acid plants have been unwisely placed, though they are not excused in law for creating a nuisance, we cannot insist upon their closure or removal. The loss in such an event would be heavy and the community itself would suffer through loss of work for labor and through curtailed production. We must, therefore, meet the situation squarely in good faith and abate the nuisance entirely, or, at least, reduce it to a minimum.

The public recourse to our courts of justice tends to hold in check a general pollution of the atmosphere or the creation of a general nuisance. What constitutes a nuisance in this country depends, however, in what state in the Union the question arises. The public itself is not always in position to know what constitutes a nuisance, especially if it is influenced by interested parties.

Legislative Status in the United States

The ideal remedy would appear to lie in federal legislation controlling the industries, defining the term "nuisance" in connection with fumes from sulphuric acid manufacture, and to what extent atmospheric pollution can be permitted without creating such a nuisance. Whether this can be accomplished in our present stage of development in this country is debatable. As the situation now stands, the sulphuric acid industry in the United States is hampered by the varied interpretation in our courts of the term "nuisance." That the sulphuric acid industry does create a nuisance at times is realized and manufacturers have not always deemed it necessary for efficient management to stop entirely the emission of noxious gases into the atmosphere. This fact subjects the industry to a continual state of uncertainty regarding injunctions and law suits instead of having the support of the public which it benefits in so many ways.

To hold in check both the inefficient operator of such plants from running wild on the one hand, and the unscrupulous lawyers taking advantage of the present legal conditions on the other hand, it should be the aim of all interested to emulate the example of

Great Britain in controlling the situation by federal or uniform legislative enactments.

The chaos in this country at present is readily understood when the decisions made in the different states regarding what constitutes a nuisance are reviewed. Local legislation appears in a hopeless situation. Baskerville[1] has pointed out that New Jersey might have one interpretation while New York might have another and so on throughout the Union, ranging in interpretation from one extreme to another. Decisions in Iowa, Massachusetts, Texas and Vermont held that a noxious trade may be a nuisance no matter how remote the locality if it inflicts serious discomfort on people passing by on a public highway. On the other hand, the city of New York has a stipulated fine for creating a nuisance, but the fact that an order of arrest cannot be made before one month from date of initiation of nuisance, and this nuisance may continue until the end of the month when the fine may be assessed, makes the ordinance ridiculous.

The smelter fume situation is somewhat similar to that of the sulphuric acid plant fume problem. In the west the smelters have been continually in conflict with the agricultural interests. Sulphur in its oxidized condition, existing in gas exits not only from sulphuric acid plants, but from any source whatever, may give rise to community difficulties under the name of "sulphur smoke" nuisances.

The nature of the fumes and odors is such that the effect of the emissions may change between wide limits due to variability of the different fumes and the variability of effect of the same gas in different plants. The action of smelter fumes and smoke containing SO_2 on vegetation has been a question of some moment since the beginning of the nineteenth century. The mechanism of SO_2 attacking vegetation and efforts to diagnose injury as due to SO_2 has been minutely studied by the chief inspectors under the Alkali Acts of Great Britain, by botanists in Germany and also in the United States, especially by parties interested in smelter fume litigation.

Judicial compromise is the order of the day in this country. In some cases, the principle of "the greatest good for the greatest number" and the collateral benefit to the community have been much emphasized and have played an important part in the settle-

[1] *Eng. and Min. J.*, 87, 884 (1909).

ment of smoke nuisance law suits.[2] Others have been settled by arbitration.[3] Compromise or arbitration, however, has not solved the problem. It appears to be the rule in case of the smelter controversy that the metallurgists have been more fair and more generous in their attitude towards the abatement of the fume nuisance than the agriculturist as the former are more conversant with the business situation and it is frequently a matter of economy with them to prevent the indiscriminate discharge of fumes, as is clearly evident at Copper Hill, and Ducktown, Tenn. Baskerville[4] gives the most thorough resumé in the chemical literature of the more important litigation cases, particularly in smelter nuisances with copious references to the literature on the subject. Most of his points will cover the sulphuric acid plant fume nuisance also. He suggests the need of some kind of federal limitation of the amount of atmospheric pollution which is permissable, and also suggests a scientific commission for the assessment of damages.

Legislative Control in Foreign Countries

The United States appears far behind Great Britain, for instance, in the legislative control of escaping fumes from chemical plants. As early as January 1, 1864, a British Parliamentary Act was in operation, not stopping but regulating the amount of hydrochloric acid gas escaping into the atmosphere from the Le Blanc Process. The Act was to lapse in 1868, but at that time it was made permanent. In 1874, sulphuric acid and wet process copper works were included without pollution limits. Two years later a committee of alkali manufacturers was appointed to watch the proceedings of the Royal Commission, who were investigating noxious gases generally. Out of this arrangement, in 1882, an enactment was made that such industries manufacturing "chemical manure," salt, nitric acid, sulfate of ammonia, chlorine and sulphuric acid, and those depositing or discharging alkali wastes and creating nuisance from fumes, were added to the list of industries to be inspected and regulated. The object of the act was to prevent damage to the health of the people in the neighborhood of such establishments. The original registration and inspection had its

[2] *Eng. and Min. J.*, 87, 265 (1909); *Met. and Chem. Eng.*, 8, 173 (1910).

[3] *Eng. and Min. J.*, 84, 561 (1906); Selby Smelter Commission Report, *Bur. Mines Bull.*, 98.

[4] [*Ibid.*]

immediate effect in reducing the acidity of exit gases from such works, and a limit was therefore set for such gases in the Act of 1881. In 1892, an amendment was made to still further increase the scope of the Alkali etc., Works, Regulation Acts. An amendment in 1901, specifying where samples should be taken in sulphur acid emitting processes, met with so much resistance that it was repealed in 1906, and more lenient methods of sample taking were allowed. In 1907, the smelters were for the first term required to restrict their output of SO_2, it being felt at this time that the status of fume control had reached such a high degree of perfection in other plants that the application of some of the principles used by these plants would be applicable to the smelter fumes and would work no hardships. No limit for SO_2 escape was made, but it was expressed that the chief inspector should investigate excessive escapes.

The chief inspector provided under the Acts of Great Britain was required to detect excessive escapes and control them. Each plant registering under the act was required to submit all information as to process and means of control, which information was not the property of the government, but still the property of the manufacturer, and all rights pertaining thereto were respected as such. The chief inspector was required to make reports annually on the progress of his supervision.

The Acts provided leniently for methods of controlling escapes, by specifying that they must be controlled "by the best practical means," which clause applied to them until such time as the Parliament felt that knowledge of control was sufficient to enable the works to keep below a certain limit by ordinary control and efficient operation.

A review of the annual reports of the chief inspector under the Alkali Acts indicates that the control of noxious fumes from sulphuric acid plants is almost altogether accomplished by efficient operation and not by special devices.

Again, in 1898,[5] sulphuric acid plant fumes seriously engaged the attention of the chief inspector. From that time on, the chief inspector has especially emphasized this industry in his annual report due to the numerous complaints.[6]

The Alkali Commission, self-appointed, also assumed control of

[5] *J. Soc. Chem. Ind.*, 17, 664 (1898).

[6] *J. Soc. Chem. Ind.*, 18, 681 (1899); 19, 742 (1900); 20, 693 (1901); 21, 1135 (1902); 22, 862 (1903); 23, 784 (1904); 24, 728 (1903), etc.

investigations on methods of analyses of these gases and fumes.[7]

The Act of 1906 requires that the samples must be taken from the chimney just after the gases leave the Gay-Lussac tower. This, obviously, gives one source of information necessary in efficient operation, but leaks occurring before the chambers cannot be checked up readily, since the quantity of acid produced from the tonnage of sulphur or ore burned would have to be known to detect these leaks by using this method alone. The quantity of SO_3 and SO_2 escaping from the burner room or leaks in a Glover tower or the chambers, for instance, may be manyfold greater than the SO_2 or SO_3 found in the chimney by such a governmental regulation inspection system.

In Germany, stringent regulations exist in various provinces for the control of sulphur fumes, but no uniform law exists for all Germany. Present practice regarding fumes is controlled by custom justified by precedent, although a license law for chemical plants has existed in Germany since 1845. According to these regulations, the licensing authorities are given complete control, and can require that sulphur fumes be prevented from escaping wholly, or in part.

The usual requirement is that the gases from the Gay-Lussac towers shall not contain more than a certain proportion of SO_2 according to the locality. In some places in Prussia, the gases may not contain more than 0.02 per cent SO_2 by volume as stated by Ingalls.[8] Wislicenus points out that the danger of such regulations in the hands of local authorities is that politics may play too strong a hand in the proper exercise of controlling atmospheric pollution.

Importance of Fume Control

In view of the above discussion of the status of legislative supervision it will be evident that the control of fume escape from sulphuric acid plants is important from the following points of view, which illustrate what it would, or might, accomplish: (1) Betterment of health conditions in the neighborhood; (2) elimination of damage to vegetation; (3) elimination of litigation; (4) improvement of production yields.

The effect of these gases on the workmen is very difficult to ascertain. After a short time these men become accustomed to the effects of the gases and they appear no longer irritated by them.

[7] *J. Soc. Chem. Ind.*, 21, 1490 (1902).

[8] *Min. Ind.*, 14, 682 (1907).

The ultimate effect on their health, however, is not known since no study appears to have been made thereon, or the matter has been given little publicity.

The good accomplished in Great Britain by Acts of Parliament and by the Alkali Commission due to cooperation does not seem to have had its influence in America except to the extent it may have raised general commercial efficiency of operation. The appointment of such a body or commission by manufacturers in this country even if our legislative bodies do not take action, should result in the saving of large sums of money as well as eliminating litigation and friction. The good work of the Selby Smelter Commission carried out under the direction of the U. S. Bureau of Mines, in investigating the nuisance created by the Selby Smelter and Lead Company of Contra Costa County, California, due to dust, SO_3 and H_2SO_4 fumes and SO_2 mainly, with small amounts of lead and arsenic compounds, should be followed up. Their report [9] is a draft of the findings in that case. However, the work done on each case, taken up in such an independent manner, as at the Selby Smelter, when too great a nuisance is created, will not answer wholly our purpose. Under the circumstances, if nothing more can be done, we must let each case or industry whose need is pressing, be investigated to the point of satisfaction to all concerned and give publicity to all results of general value. We should not feel that this need exists, however, among smelters only. Sulphuric acid plants are more and more frequently affected than in the past.

That the fume problem from sulphuric acid plant is a real one may be deduced from the operation data of a certain sulphuric acid plant, which has recently been sued in court for damage done surrounding farm lands. During the period from January 1 to June 30, 1920 (inclusive), 13,986 tons of chamber acid were produced. On the basis of sulphur burned, for the same period of time 902 tons sulphuric acid were lost. Therefore, it was calculated that about 229 tons of sulphur may have been dissipated into the air through leaks in chambers, backfires in burners, or through the exit flue. This was a percentage loss of 6.06 per cent from the sulphur used, or a pollution of the air to the extent of 5046 pounds of SO_2 per day, or in the neighborhood of 30,000 cubic feet if all the loss followed this route. This could not be entirely true, though much did go this way. The loss at this plant is high, but

[9] Bur. Mines Bulletin No. 98.

not necessarily much above the average practice throughout the United States, though at most plants the loss is probably little due to SO_2 escape. Thorpe[10] states that the yield in practice from burning brimstone averages 96 to 98 per cent.

Brief Review of Past Efforts at Amelioration

The smelter industry having frequently been the greater transgressor, has had much experience of value to us. Smelter fumes consist of SO_2, volatile arsenic and dust containing Zn, Pb and Cu and sometimes H_2SO_4. From sulphuric acid plants, SO_2, SO_3, H_2SO_4 and oxides of nitrogen may be emitted through leaks or the regular tail-gas exits. That these gases may be and have been the direct cause of damage to vegetable life does not admit of contradiction. It appears to have been proven pretty thoroughly that it is possible to prevent the discharge of SO_3 and solids, but it may be asserted in the present state of the art, no reasonable and effective method has been proposed to prevent large quantities of SO_2 from escaping and doing damage. In the case of abating any nuisance, the additional problem is frequently presented of making by-products of sufficient value to offset the cost of their recovery so that, if possible, the net cost of operation shall not be increased. The extensive scientific and other expensive experimentation carried on at the Anaconda smelters indicates that the elimination of quantities of SO_2 still awaits the commercially demonstrated successful process.

Attempts have been made to control and abate the fume nuisance at smelters by a variety of methods. The elimination of dust by bag houses is a general practice. The life of the bags, however, is short if the SO_2 and SO_3, or H_2SO_4 are not previously neutralized. The neutralization of SO_3, or H_2SO_4, is accomplished by the Sprague process of passing the fumes over roasting zinc ores and by injection of lime into the flues.[11] SO_3, or H_2SO_4, is also eliminated from fumes by Cottrell electro precipitation methods. Water and steam jets for elimination of SO_3, or H_2SO_4, and solids are also suggested.

With respect to SO_2, the situation is more difficult, due to the chemical nature of the gas. In some instances, court rulings have

[10] Dict. of Applied Chemistry, Vol. V, 1912. Longmans, Green & Co., New York, p. 327.

[11] *Met. and Chem. Eng.*, 8, 173, 203 (1910); *Eng. and Min. J.*, 89, 519 (1910); *Met. and Chem. Eng.*, 9, 218, 423 (1911); *ibid.*, 12, 616 (1914).

regulated the extent of pollution by ordering curtailment of production, so that the amount of SO_2 pollution may not exceed a specified quantity. Other plants have striven to keep down the ratio of SO_2 in the air by dissipation of gases by means of large stacks, and by the use of the Wislicenus lattice-top smoke stack.[12]

Chemical absorbents such as water, sulphuric acid, metallic oxides, and hydroxides, di-calcium phosphate, silica gel, lime and limestone, moist scrap iron, charcoal, tetrathionate, and such materials have been suggested but not extensively put to practical use.

The recovery of sulphur from SO_2 by reduction with carbon and the application of the wet and dry thiogen process on waste SO_2 gases has received some commercial consideration, but are not sufficiently developed to be considered an answer to the SO_2 fumes problem.

The preparation of sulphuric acid from SO_2 fumes by the installation of H_2SO_4 plants where economical, due to favorable market situation and demand for acid locally, seems to be the most desirable method for SO_2 elimination from smelter fumes. The Tennessee Copper Co. and the Ducktown Sulphur, Copper and Iron Company operate such plants. Because of the high dilution of the SO_2 gas, mechanical water concentrators have been suggested in addition to the chemical absorbents mentioned above.

Because of high dilution of the SO_2 gas, chemical absorbents with various mechanical devices to bring about intimate contact of the gases and absorbent have been suggested. These absorbents claim to be such that the SO_2 can be driven off again, and the concentrated SO_2 be utilized for sulphuric acid manufacture.

Refrigeration of the SO_2 after proper purification has proved of commercial value in at least one plant in the United States, and also in parts of Germany, where great quantities of SO_2 are used in cellulose manufacture.

The oxidation of SO_2 by Cl_2 to produce HCl and H_2SO_4 by the Greenwalt process[13] has not been applied commercially as yet.

Even if any one of the above were a commercial success, as the Tennessee cases undoubtedly are, the smelter fume solution would not necessarily solve the sulphuric acid fume problem in its entirety. Enforcement of efficient management will also be necessary in the latter situation.

[12] *Met. and Chem. Eng.*, 9, 606 (1911); *J. Ind. and Eng. Chem.*, 5, 425 (1913).
[13] *Eng. and Min. J.*, 90, 1062 (1910).

The Determination of Atmospheric Pollution

Bad management appears to be frequently the cause of excessive fume distribution over a community by a plant using SO_2 or SO_3 in some form. Even in efficiently operated plants, however, as indicated by the Chief Inspector's Report of the Alkali, etc., Works Regulation Acts, the fume problem arises to varying degrees of annoyance and has not been solved. Some plants in this country are so well managed that seldom, if ever, are they a nuisance. In operation, a leak may escape notice of the employees, because their sense of smell has been attuned to these odors, while the effect on people outside of the plant may be considerable. Therefore, the sense of smell cannot be relied on. Proper methods of control in the plant, able to detect any undue loss or escape of constituents, are essential in fume-efficient operation of sulphuric acid plants.

The analysis of the neighborhood atmosphere is necessarily the first consideration in any investigation of this kind. At present, the iodine and $KMnO_4$ oxidimetric and the alkalimetric methods are employed in attempts to detect and evaluate escape of gases and check operation of plant. These methods, however, are known to be not as reliable as they should be. A thorough study of the literature indicates that much of the knowledge on the subject is based on assumption and not upon fact.

The Iodine Method.—During a recent investigation in this laboratory of the fume emitted from one sulphuric acid plant, a reliable method of determining the amount of SO_2 was sought. The iodine method depends upon a standard solution which in itself is unstable. The method was modified by Marsden and this modification was used by the Selby Smelter Commission. It consists in titration of samples of SO_2 in excess iodine back to the original depth of color as indicated by a blank. Excess iodine must be present at all times in the sample bottle and the iodine solution must have some SO_2 dissolved therein, so that the color produced by SO_2 oxidation will not cause difficulty in color matching. Therefore, it is best to use the iodine solution over and over again, but with the blank and sample mixed after each run to equalize the color. However, the instability of the iodine solution and the different action of iodine under varying concentrations of SO_2 or the oxidized products of SO_2 gas and in solution, make the method appear not as accurate as desired, nor has it ever been developed for high concentrations. Considerable difficulty is also encountered

by beginners in using this method and it is very cumbersome for field work. In these laboratories, however, fair results have been obtained with the method, and its limits of accuracy are being worked out.

Silica Gel.—The new development of silica gel by McGavack and Patrick [14] for the absorption of SO_2 may open up possibilities for a new line of development in solving the SO_2 determination problem. Our investigation has not included it.

The Permanganate Method.—Since $KMnO_4$ is supposed to oxidize sulphur-dioxide completely, it has been suggested as a substitute for iodine in SO_2 determinations. Work was therefore started, using the Dymond and Hughes' $KMnO_4$ equation as the basis.[15] This equation runs $17H_2SO_3 + 6KMnO_4 = 2K_2S_2O_6 + K_2SO_4 + 6MnSO_4 + 6H_2SO_4 + 11H_2O$. At that time the method was thought reliable, but checking over the work revealed how erratic the method really was. Subsequent to this and at present, six workers in this laboratory have been investigating this problem from various angles under a research appropriation by our Engineering Experiment Station. An effort at the correct understanding of the chemistry of the reaction between SO_2 and $KMnO_4$ is being made. The manipulative details of this method to make it reliable have not been found as yet. It is desired that this paper provoke interest and discussion of the problem of supplying a reliable SO_2 method easily handled by even junior or inexperienced chemists.

SO_2 Standards.—Obviously, the peculiar chemistry of sulphur oxidation derivatives makes dependence upon ordinary reduction standards unreliable in checking oxidizing reagents to be used for SO_2 determinations. Efforts were early directed towards the preparation of a suitable standard by which the desired methods could be checked. The difficulties met with here are manifold, although the effect of small errors in the standards have not the great influence on the results that is generally surmised. The great difficulty encountered to date has been inequality in results with the same standard solutions. It appears that the difficulty cannot be credited to any one factor. A number of factors influence the results, each slightly, one way or the other, but the effect is collective.

[14] *J. Am. Chem. Soc.*, 42, 946 (1920).
[15] *Jour. Chem. Soc.*, 71, 314 (1897).

Experimental Investigation Under Way.—A brief review of the work that has been completed, and that which is being carried on, in this laboratory may be of interest.

i. The first effort was to replace the Marsden iodine method for SO_2 determination of the Selby Smelter Commission, already reported by Sweeney, Outcault and Withrow.[16] The idea was to use the permanganate method of Dymond and Hughes.[17] With this effort we are dissatisfied, due to inability to obtain checking results by different operators.

ii. The next effort was an attempt to study the effect of the standards on the results. This endeavors to point out the desirability of using a weighable sulfite, preferably the heptahydrate of sodium sulfite, which is mentioned in the literature for standardization purposes.

iii. The next effort was a second endeavor to study the $KMnO_4$ method for SO_2 titration, using the color matching scheme, with excess $KMnO_4$ in acid solution.

The Need for Cooperation on the Sulphur Dioxide Fume Problem

A cooperative committee of the chemical industries, perhaps best organized through this Institute, or the matter taken up by a commission from this Institute, subsidized by the manufacturers, would enable America to progress rightly in this question and assist in solving the fume nuisance not only from sulphuric acid plants, but from all chemical industries evolving SO_2 and other noxious odors. If the Institute does not initiate it, this will come by bunglesome legislation; nothing can stop it. Therefore, the sooner the question is met, the greater convenience the chemical industries will be to the communities at large and the better will trouble with these communities be evaded.

This laboratory will, in any event, continue to make such contributions to the solution of the SO_2 problem as it is able.

This whole problem is closely connected with that of industrial health hazards that is receiving able attention but its economic and business relation to the community makes this a broader question than health hazard merely, important as that matter may be.

[16] *J. Ind. Eng. Chem.*, IX, 949 (1917).

[17] *Loc. cit.*

Discussion

The President: We have all listened with a great deal of interest to Doctor Withrow's paper. It is now open for discussion.

Doctor Reese: I did not hear the first part of this paper, but what is the matter with iodine?

Doctor Withrow: The first part of the paper suggested that iodine is the best solution we use. It gives a great deal of trouble however, working with weak solutions. It is very difficult to keep them of constant composition.

Secretary Olsen: I would like to ask one question, which you may have covered while I was out, but did you give the minimum amount of SO_2 which will be a nuisance?

Doctor Withrow: Every state has its own ideas, and apparently every court which handles the situation has its own ideas.

Secretary Olsen: Well, did you give anything definite on that?

Doctor Withrow: No, sir, we do not suggest limits. That is the problem.

Secretary Olsen: So far as I have been able to determine—and I have had to study this somewhat—a very minute amount of SO_2 becomes a nuisance, for the reason that after being collected and dissolved with rain water and things of that kind, it will go down and produce quite corrosive effects.

Professor Williamson: I might say that in 1915, I had occasion to do some work at the Ducktown plant in Tennessee, and I found two very interesting facts. First, I did not find any SO_3 in the stack gases, if the solution of barium chloride used as absorbing liquid were boiled out in the dark on the electric hot plate, but I did find SO_3 if they were boiled out in the presence of electric light over a gas flame. Second, that the curve for sulphur dioxide concentration in the atmosphere fell consistently in this (illustrates on board).

At a two-mile distance sulphur dioxide disappears. Of course it would disappear more quickly in a damp atmosphere like this in New Orleans and more slowly at a greater altitude of 1600 or 2000 feet, in the Ducktown vicinity.

At a distance of two-miles from the plant, there was no SO_2, a drop from 342 parts per million, where I was able to take the sample.

The concentration of SO_2 was 342 parts per million in the atmosphere within 50 yards of the stack. I do not remember the concentration of SO_2 in the gases coming out of the stack, but this was taken as near as possible to the stack, because we were trying to

get at the damage to the workmen, as well as the alleged damage to the Georgia farmers two and a half miles away.

I took up the Marsden process which had been developed by Marsden at Selby, and which had been exploited by Holmes Gould and Franklin and worked, instead of with 24 liters, with 6 liters.

I found that I could detect accurately to the sensitiveness of 18/100 parts per million of SO_2 using N/500 iodine, provided the blank bottle was subjected to the same conditions to which those containing the samples, such as sunlight, shaking etc., with the exception that the blank bottle was not evacuated.

I did not hear the oral part of Doctor Withrow's paper, but I do wish to point out an important point with respect to absorbing gases which is, in aspirating a gas of several components through an absorbing liquid absorption is not usually complete, those components which are present in minor amounts escaping absorption.

Errors may arise as a result of the method of collecting the samples, and I found a large error was introduced in this case by aspirating the gases through the iodine. The mists or vapors of sulphuric acid may pass through a caustic alkali solution without complete removal, if their concentration is sufficiently low in the gas being aspirated.

DOCTOR REESE: Have you found that true with sulphur dioxide?

PROFESSOR WILLIAMSON: I did find it true with sulphur dioxide. I was not especially interested in the absorption of sulphuric acid vapors because the Georgia line was 2.8 miles from the smelter and if we notice the curves at the two-mile point we see there was no danger of sulphuric acid except floating down through a little stream there.

MR. MOORE: I think this question of fumes is in many cases largely psychological, or depending on a man's point of view. I might mention innumerable cases, but we will take one illustration: Suppose a mill knows that its process is going to subject the community to fumes. That mill immediately establishes its plant up in a wilderness, where there is nobody—even no roads entering the place. They give employment to the town. The people of the town are all dependent upon that mill. By and by land which is not worth twenty-five or fifty cents an acre becomes valuable. Then real estate men wish to come in and sell land say 100 feet by 50 feet at anywhere from two hundred to five hundred dollars a lot. They immediately raise the question of a fume nuisance and

so forth, in order that they can make a profit out of something which the mill has made. It seems to me that they have lost their rights. (Laughter.)

SECRETARY OLSEN: Would that go in law, Mr. Moore?

MR. MOORE: I think it will.

DOCTOR WITHROW: That is the trouble. It does go. This illustrates exactly the point that we want to bring out here. The industries need protection against that sort of thing. And of course we have got to do the right thing by the public, too. It is mutual and it must work both ways.

I will give a little experience of how easily SO_2 disappears, from an experience of about four months attempting to prepare a standard SO_2 gas. That can be done, but it is hard work. You can take a sample of air containing a known amount of SO_2 and pass it through a right angle bend of glass and lose 15 per cent of the SO_2 content. And that is probably explained by the fact that in impinging against the wall, it sticks there in adsorbed moisture and the gas is robbed of just that much SO_2.

Now, regarding ability to pass fog SO_3 through solution without it being absorbed is well known, and that was one of our troubles in the contact sulphuric acid process. We explain that by saying "colloidal" of course. It is not subject to the laws of gases, and the consequence is you have to have literal contact to get it out. Therefore sulphuric acid in gas could only be gotten out by literal contact with some absorbing surface.

DOCTOR REESE: I would like to raise a point about absorbing gases. You can certainly absorb SO_2 or SO_3, but you cannot absorb sulphuric acid mist. If you will pass sulphur dioxide through 98 per cent sulphuric acid, or acid that has not got a water vapor tension, you will absorb every bit of it. I have had a good deal of experience in sulphuric acid plants, and if you use an acid without a water vapor tension, that is, where it has a strength that does not give off water vapor, you can absorb every bit of it and the plant will discharge absolutely no fumes at all.

PROFESSOR WILLIAMSON: What I was referring to when I said you could not absorb the vapors of sulphuric acid was in reference to the general analytical reagents and analytical processes which are employed when sucking the gases through absorbers.

MR. MOORE: In this question of absorption, I think there is a question that I do not think is fully understood, but I think it

depends largely on the size of the particle. For instance, you take mercury. It is 30 times as heavy as water. Now, you can get mercury so fine that it will practically float all through an equal emulsion, I might say, of water, if I can use that term. Probably the explanation is that as you decrease the size of the particle, you increase the relative amount of surface in relation to the volume, and after a while you reach a certain limit, where your electrical repulsion charges are such that they tend to keep every particle equidistant from every other particle, due to certain static electricity which is concentrated in the surface, and consequently the particles tend to assume the cubical form rather than the plane surface form.

DOCTOR SMITH: Mr. Chairman, there is just one other point I would like to call attention to in Doctor Withrow's paper, and that is the damage done by power plants.

There is a very beautiful grove of trees on the shore of a lake at Cleveland that has simply been destroyed in the last ten years by the acid from power plants.

DOCTOR WITHROW: I would like to ask whether that is due to sulphuric acid or some other acid. For instance, I can remember many years ago a grove of English walnut trees around a race track at Philadelphia. They built a brickyard nearby, and those trees all died within the course of three or four years. They did not seem to be able to stand anything at all in the way of those fumes, but it seemed to be due to something else in those fumes rather than the sulphur. Other trees in the neighborhood were not affected, but these trees all died.

DOCTOR SMITH: I think in this case there is no question about its being sulphuric acid. You can scrape the bark anywhere and find the free acid there. The trees in that immediate vicinity are dying, and nearly all are dead now, while the same kind of trees, the same age and nearly all the conditions the same a quarter of a mile away are just as good as ten years ago.

DOCTOR WITHROW: That case apparently must be certain. But we are using a great deal of sulphur compounds on delicate trees now, so there must be a concentration that plants can stand, and beyond that a concentration that they cannot stand.

PROFESSOR WILLIAMSON: I would like to bring out also that sulphur dioxide and sulphur trioxide are not the only ones of the family of sulphur compounds coming out of a stack which can do

damage. I had a very interesting case here in New Orleans of damage from a plant burning fuel oil carrying 5 per cent of sulphur and the damage of hydrogen sulphide was first called attention to by the formation of copper sulphide on a brass lantern hanging in a tree nearby. I made an investigation and found that hydrogen sulphide was a very serious contributor to the damage done in this case.

SECRETARY OLSEN: Mr. President, I think Professor Withrow's suggestion about our having a committee on this subject should not go without action. I think there are two things he suggested for a committee of that kind to take up. One was the actual damage done, and the other was studying this matter of legislation, and it looks to me as if it would be very profitable if we did have a committee which would report at our next meeting on these two phases of the question.

If the chemical industries are being treated as our friend Moore here suggests, to create values and then be compelled to pay twenty times over for the land, it looks to me as if we should make some protest.

It seems to me this society is the society to take that matter up, and I move, just to get it before the house, Mr. President, that a committee of three or five be appointed in accordance with the suggestion of Professor Withrow and be called the "Chemical Fume Committee." If there is any better name, that anyone can suggest, why, all right.

THE PRESIDENT: Gentlemen, you have heard the motion, is it seconded?

The motion was duly seconded.

THE PRESIDENT: Is there any discussion?

DOCTOR SMITH: I would suggest that you call it the "Atmospheric Pollution Committee."

DOCTOR LANGMUIR: I do not think the Chemical Engineers should go on record as being in favor of air pollution, and whether it is necessary or unnecessary. I presume the public is of one mind on that and will not stand for it. It seems to me we should solve the problem and not go on record as excusing it.

SECRETARY OLSEN: We do not go on record as approving it. I ask the committee to find out what the equities of the case are. If the chemical industry goes and puts up a mill somewhere where there is no one living, and attracts population, and then is assessed

for damages, that is clearly a case of equity, and if there is to be legislation on this question, I certainly believe in our legal procedure. We want both sides heard, and I certainly believe that the American Institute of Chemical Engineers is the Society which will present the equities from the standpoint of the chemical industries. Not for one minute do I say that we shall excuse it.

DOCTOR REESE: It might be of interest to the members here to hear of a little thing that happened during the war that Mr. Howard is familiar with.

The directors of the Chemical Alliance met in Washington every month, and at one of their meetings, they found that a rider had been put on one of the appropriation bills to stop pollution of streams with acid, which would have resulted in putting into the hands of the President the power to shut down every chemical factory in the United States. I happened to be put on the committee to try to kill this legislation, so I made a little investigation of it. It was brought about by some Army officers who had charge of the work on the Ohio River, the Alleghany and the Monongahela running into it, and there are certain locks on the rivers which have iron hinges and apparatus which became very badly corroded due to acid in those rivers. I figured out, after getting some data, that practically all of that acid, or the larger part of it, came from the coal mines in Pennsylvania, Ohio and West Virginia, and probably the most of it came from abandoned coal mines. Now, these fellows were going to pass a law that would make it a criminal act to allow the waters from the abandoned coal mines in Ohio and West Virginia to run into the Ohio River.

I figured out that it would take all the lime that was manufactured in the United States even during the war period to carry that to that point to neutralize that acid, and that it would take all the railroad freight cars we had in the country to carry the lime to the Ohio River to neutralize that acid. It is perfectly astonishing the amount of sulphuric acid that goes into the Ohio River from that source.

Now, the chemical industry in this country is a mere bagatelle as compared to that water.

Now, after presenting that matter to the authorities, we managed to get that taken out. We were not able to convince the army officers, but by seeing the senators and representatives we had it taken out. It was the most outrageous proposition I have ever

heard of, and right in the midst of a war, when you had more chemical plants operating in this country than we had ever before or probably ever will have again, we had a proposition to stop those plants.

DOCTOR HOWARD: I think the total value of the hinges damaged was less than twenty thousand dollars.

DOCTOR REESE: I told the army officers if they would put gold hinges on there, it would be much cheaper than stopping those plants. (Laughter.)

DOCTOR REESE: We had a problem in West Virginia. We were making a million and a quarter pounds of nitro-cellulose a day, and we found that the acid would back up in the creeks and the cows would die, and in order to avoid that sort of difficulty, and as the British Government and the French and the Italians and the Russians were paying for this powder, we actually hauled trainloads of lime to that plant and neutralized all the acid waters that ran out of that plant into that river during the period of that manufacture, so that I knew exactly what it meant to do that with acid waters.

Now, it is an interesting fact that I have been interviewed by officials of some of the subsidiaries of the Pennsylvania Railroad since that time, because they are having great difficulty in getting water to run the locomotives on the Pennsylvania Railroad in Western Pennsylvania free from acid, and it is a very serious problem to-day and I do not know how to solve it.

SECRETARY OLSEN: I want to say, Mr. President, in answer to Doctor Langmuir, that I am thoroughly in favor of his attitude that we should not pollute the atmosphere. I do not want to leave the impression at all that I made that motion on that basis.

DOCTOR WITHROW: In corroboration of what Doctor Reese says, I have actually taken samples in Ohio that have eventually gotten into the Ohio River, where the bottle, within half an hour, was crystallized all over the outside, indicating a very strong acid solution.

DOCTOR REESE: I have made some investigation and found that all that water is actually neutralized before it gets to some point—I don't remember what point—on the Ohio River, neutralized naturally. Before it gets to Louisville, or probably Cincinnati, that water is all neutralized by the waters which come mostly from West Virginia, I imagine from the limestone districts.

DOCTOR HOWARD: There is one other side of this question that I think ought to be touched on, and that is that history shows that in many cases companies have been forced into the stopping of pollution and that new products and new processes have resulted that have been most profitable, and that the manufacturer generally protests against it, but in a great many cases, in the long run, it works out strongly in his favor, making him carry out his processes more efficiently. If you will read the history of the Alkali Act in England, you will find that is almost universally true. And in fact, the Tennessee Company's huge production of sulphuric acid is a point we are all familiar with, which is a point right in that line.

DOCTOR REESE: I had that also in mind. I am glad that Mr. Howard mentioned that question. As another illustration of what Mr. Howard says, we are making sulphuric acid near Tacoma to-day out of liquid sulphur dioxide that is prevented from going over the country there—at the Tacoma Smelter. It is a very nice product to make sulphuric acid out of.

THE PRESIDENT: Traveling out in California a few years ago, I met a gentleman on the train and he bragged a great deal about his splendid orange grove at Riverside, and how much money he had been making out of it. A few months ago I met another man who told me that this man has been making more money out of suing the cement works than he has out of his oranges.

The question is before the house, gentlemen. All in favor signify by saying "Aye"; contrary "No."

It is a vote.

RESOURCES OF THE STATE OF LOUISIANA

By M. L. ALEXANDER

Read at the New Orleans Meeting, December 6, 1920

Louisiana, through its Legislature, has recognized the necessity of safeguarding for the future the great resources of the State, and has passed wise laws for their protection. The State has created a Department of Conservation which is declared under the law to be a department of the State, and placed in charge a Commissioner of Conservation whose duty it is to enforce these laws and to guard and protect the resources of the State.

Louisiana is a wonderful state, with its 45,000 square miles of territory and something over 28 millions of acres of land, with its ideal climate and fertile soil, rich in history and romance and natural resources, and it is the natural resources that I am going to talk to you about to-night.

The Forests of Louisiana

Louisiana stands second of all the States of the Union in the production of lumber. We produced last year over 200 millions of dollars worth of lumber, with something like 450 or 460 saw mills in the State.

Louisiana has the greatest saw-mill in the world, the Great Southern Lumber Company of Bogalusa, and it takes approximately 65 acres of virgin pine forests a day to feed that one mill, which has a capacity equal to 1,000,000 feet of lumber per day. We are proud that this great industry is here in the State, but we are alarmed at the fact that these great virgin forests of Louisiana are being cut away so rapidly.

We estimate now that the pine forests will not last more than 20 years at the rate of the present cut. We estimate that these great cypress forests of Louisiana—and Louisiana leads the world in cypress, or leads all of the States in the Union, and possibly 40 per cent of all of the cypress which is left standing in the United States is within the borders of Louisiana, and still, that wonderful wood is being cut away so rapidly that within a period of fifteen or eighteen or twenty years it also will be gone.

Now, we recognize that something must be done to reforest these denuded acres, and we are putting in, in the State, a constructive forest policy.

We have in Louisiana an experimental forest reservation. I have taken, under contract with one of the great lumber companies of the State, some 80,000 acres of land and guaranteed them for a period of 40 years that their assessment will not be over $1 per acre, provided they prepare that land to grow pine trees. That is known as the Urania forest.

Now, that forest has attracted such attention that the Yale forestry school has graduated two of its classes there. They graduated their 1917 class there and their 1920 class there. In the 1917 class there was a young man from South Africa. They have men from all over the world. In the 1920 class they had some Chinese there, and this forest reservation of Louisiana is attracting a great deal of attention, and Colonel Greeley, Chief Forester of the United States, was here two weeks ago—came down here specially to see this great experiment we are carrying on to convince the lumbermen that it is practicable to reforest the denuded lands in a reasonable period of time, which we say is from 35 to 40 years on the lower grades of pine.

Now, we have had a wonderful demonstration of the value of this, because we have been able to demonstrate to this great lumber company at Bogalusa and its owners, the Goodyears, the possibility of growing trees not only for the making of lumber, but for the making of wood pulp.

The whole Goodyear family came down three weeks ago by special car directly to the Urania forests to see what we were doing there, and we demonstrated to them beyond the question of doubt that in fifteen years' time you could grow trees sufficiently large for pulp wood.

They have a paper mill at Bogalusa that cost something over a million or a million and a half dollars, and Mr. Goodyear told me when he left that they would immediately authorize the expenditure of eight millions of dollars more, within the next five years, in erecting paper mills, and that they were going into the business of growing trees; that their cut at that particular mill and their holdings now would only last 25 years, and that they were very much interested in the whole condition over there and they did not want it to go to smash as the ordinary lumber interest does after

they are cut out, and that, therefore, if they could not grow trees, to feed their mills, they could at least grow trees to feed their paper mills.

That is one of the practical results that we are having from this one demonstration in the State. The other result is that we are going to educate the lumbermen as to the absolute practicability of reproducing pine forests, and we are going further than that; we are going to now organize boys' clubs. You have heard of boys' corn clubs and boys' pig clubs. We are organizing in the State to-day, through the Department of Conservation, Boys' Reforestation clubs, and we say to a farmer who owns some of this still land that is not good for agriculture and will not produce anything but trees, we say: You have 40 or 60 or 120 acres of land there. If you will turn that over to your boy, give him the authority, and the right to protect it, and let the trees grow up with the boy, then, when the boy grows to manhood, he has got something that will be worth something to him," and in that way we hope to bring about a great deal of reforestation in the State.

The State has something like 12 millions of acres of denuded land now, and that is what we are trying to do in the forestry department.

Now, in the Game Department of our work, the game division of our work—and gentlemen, we have the greatest game resources of any section of the country—do you know that 75 per cent of the nation's game spends the winters with us here in Louisiana? Do you know that we have the greatest game preserves in the world? along down here bordering on the coast of the Gulf of Mexico, where we have 300,000 acres set aside for the resting place for the wild waterfowl of the country, recognizing not only our obligations to our own people, but our obligations to you and all the people of the United States, because these ducks that breed up in Canada migrate on down to this country and spend the winters with us here in Louisiana, and we are trying to protect them against slaughter.

Now, in all the sections of the State, we have deer and bear, fur-bearing animals, and a great variety of game. The fur-bearing animals produced in the State last year over three and one half millions of dollars in pelts alone, and we are protecting them so that this industry will be perpetuated and so that these animals will be here for generations to come and the people of the State will enjoy them.

Game Preserves

After a little, I am going to take the liberty of showing you just one reel of the wild life conditions in the State, so you will have some idea of what these great preserves are.

Just a few weeks ago—these preserves are the gift of philanthropists—Mrs. Russell Sage, or the Sage Foundation deeded to the State, something like 76,000 acres of land, what is known as Marsh Island. The Rockefeller Foundation gave us 88.000 acres of land, and Mr. McIlhenny something like 60,000,and other small areas that make up something over 300,000 acres set aside for this purpose.

Now, the great purpose of that is that these wild game will have a place where they can come and rest after their long flights, and then they are distributed out in the feeding grounds.

Now, the fishing resources of Louisiana are also very great. Louisiana has 4,700 miles of navigable streams, approximately 800 miles of coast line, and innumerable lakes, bays and bayous and lagoons scattered throughout the State, and these are all teeming with the very choicest varieties of fish and sea food.

Our fresh-water fish industry last year amounted to something over 3 millions of dollars. That was the coarser species of fish, such as catfish and buffalo and things of that character. The salt-water fish resources, including the finer species of salt-water fish, and the crabs and turtles and shrimp amounted to something like three and one half millions of dollars. Then the oyster resources of Louisiana, which we consider greater than any other State in the Union, Louisiana has something like half a million acres of lands which are available for oyster culture, and we are gradually putting it into cultivation.

Louisiana produces the best oyster that is produced in the United States. It takes about 20 to 24 months to grow a marketable oyster in Louisiana, where around Baltimore it takes about three and one half years, so we can produce two crops of oysters almost in the time that it takes to grow one crop in that section.

Our oyster resources last year amounted to approximately five millions of dollars.

Now, the subject that I am going to discuss with you more intimately, possibly, than these others that I have touched on, is that of the mineral resources of Louisiana, a subject you are possibly more interested in than you are in the other subjects.

Sulphur and Salt Deposits

The mineral resources of Louisiana are very great. Louisiana had never been recognized as a mineral State. You gentlemen had possibly not known of the great mineral resources of this section. As you have been told, we have the greatest sulphur mine in the world—I understand you are going down to visit it, the sulphur mine of Calcasieu Parish, about 18 miles from Lake Charles.

This sulphur is found at a depth of about 700 feet, and mined between 700 and 750 feet. The area is small, covering only about 65 acres. The sulphur lies under a very heavy deposit of quicksand. Many companies exploiting this sulphur years ago went broke, I think an English Company, an Australian Company and a French Company. Special machinery was imported from France to see if it could not be mined. It was impossible to get it out of the ground until a patent process was invented by a German-American engineer by the name of Herman Frasch. He inventeg the process of liquefying sulphur before it was brought up, pumpind superheated water into the ground, drilling deep wells down into the sulphur rock and then pumping this water at 325°, I think it is, and sending it down into the bowels of the earth, the sulphur is melted, and then it is brought up in liquid form. The sulphur is then run into pans, and when it comes into contact with the air, it soon solidifies and becomes perfectly hard sulphur rock. It comes out 99.8 per cent pure, I think. It is really a wonderful proposition, and I am sure you will be very much interested in going down there.

Now, they mined during the last year of the war, when there was a great demand for the sulphur, something over a million tons of sulphur from the mine. The supply seems to be almost inexhaustible.

Now, also situated down in the southwestern part of the State, gentlemen, are the great salt mines of Avery and Weeks Island. I understand you are also going there. These are the greatest salt mines in the Western Hemisphere,—great mountains of salt that rise up out of the sea, just bordering on the Gulf of Mexico. The salt comes within about 90 feet of the surface. It is mined at 600 feet. There is no scaffolding in the mines except the actual scaffolding that goes into the elevator shaft that takes you down. The salt is blasted out and it analyzes 99.9 per cent pure rock salt. And they have made test borings of these deposits, something like a

thousand feet below the place where they are now mining salt, and it is also said to be solid salt. So we think there is enough salt in Louisiana to last these United States for many thousands of years to come.

Now, we have other minerals in the State that we have not paid much attention to yet. We have a great deal of lignite. Also our clay deposits are very fine indeed. They have not been exploited very much as yet.

We have a wonderfully good quality of sand for glass sand and building sand, and we have great deposits, in our rivers, of gravel and shells.

The Shell Reef

I am just now bringing into development a shell reef which I am very much interested in. Down at the mouth of the Atchafalya River, which is one of the rivers in the central part of the State entering into the Gulf of Mexico, there has been builded for generations, piling up year after year, a deposit of oyster shells, and after these oysters reach about half growth, then the freshets of the river come along and kill them out, and therefore, for generations, they have been building up, piling on top of each other, and then a little layer of mud, and then the next season a layer of oyster shells, until there has been built there a reef which we estimate has 50 million cubic yards of oyster shells in it.

I leased that reef about six years ago to an enterprising fellow who thought he could get it on the market, and he has spent something like $20,000 or $25,000 in trying to do it. He has just brought about a satisfactory result. In other words, he has interested capital in it and they are now building a plant to get out these shells and manufacture them into poultry food and building material and lime and whatever there may be in it. I think he is going to grow rich on it, as well as the men who went into it and put out a great deal of money on it. It was New York capital, I believe, that finally got behind it.

But just think of it! 50 million cubic yards of these shells that have been piled up there, 15 or 20 miles of this reef, over 40 feet deep. He tells me he has gotten orders now for over a hundred carloads of poultry food. They grind them up and make poultry food out of them.

Now, here is an added asset that has existed in the State for generations that is going to come to life, and under the contract

that we have made on this lease, it should bring in for the State something like two millions of dollars on the investment, or rather, for having leased it.

Petroleum

Now, one of the greatest assets of the State, gentlemen, in its mineral department, is the production of oil. I hardly think that you realize that Louisiana is a great oil-producing State. Louisiana produced 17 millions of barrels of oil last year, but Louisiana is going to produce over 30 millions of barrels of oil this year. Louisiana ranks fourth to-day in the oil-producing states of the Union.

At the valuation of $3 a barrel, 30 millions of barrels that would be 90 millions of dollars.

Now, one of the most remarkable fields we have in Louisiana is the Claiborne Field, and it is one of the newest. The oil is produced from two distinct strata, one at about 1,000 to 1,100 feet, that is bringing in a high-grade oil, and the wells will range all the way from 500 barrels to over 2,500 barrels. The other strata is from 2,000 to 2,300 feet, also bringing in the same high grade of oil, and the wells have been running from 1,000 barrels to 30,000 barrels, and the field is holding out remarkably well. It produced last month over two million barrels of oil from that field alone.

So you see, Louisiana is coming to the front as an oil-producing state and Louisiana is guarding carefully this great asset of the State to see that all proper methods are used in the exploitation of this field and the protection of this field against being destroyed from improper methods, or from salt water or things of that sort.

Natural Gas

The next great thing is our natural gas asset, and it is a question, gentlemen, in which I am more deeply concerned than any over which I have supervision, so to speak, that is, the protection of this great asset, which, after all, we think primarily belongs to the people.

We do not want the condition to be brought about in Louisiana that has been brought about in other states, that the great natural gas assets will be wasted. Now, for instance, we have a field in North Louisiana, known as the Ouchita-Morehouse field. It is about 30 miles long and about 18 miles broad, and in the four or five years since this field was brought into life, there is only one

well this past season that has failed to be a producer. These wells are coming in at the rate of anywhere from 4 million to 40 million cubic feet of gas per day. The carbon plants are coming in rapidly. We have ten carbon plants in that district now that are using 70 million cubic feet of gas per day.

This great City of New Orleans, with its over 400,000 inhabitants, does not use over 10 million cubic feet of gas per day.

If we do not put a check upon the carbon plants, in a year's time there will be 20 carbon plants in that field which will use 100 million cubic feet of gas per day. There is a wonderful supply of gas in that field. The pressure ranges from 1,000 to 1,180 pounds.

I suppose you know a great deal about the manufacture of carbon. You know that a plant that will cost a quarter of a million dollars to erect after it is put into operation will not employ possibly over fifteen men. The whole operation is automatic and mechanical. It means nothing as an industrial proposition for the upbuilding of the State or its communities, and a carbon plant using 10 millions of cubic feet of gas per day, as I say, will only employ 15 men, and cheap ones at that, outside of the foreman.

On a recent investigation, I found a glass plant being erected at a little town called Bastrop, in the Morehouse Field. I inquired of this man how many people they would employ. He said they would employ 250 high-class people. I said: "How much gas will you use?" "We will use less than 1 million cubic feet of gas per day."

Now, is it not better to reserve some of this gas for building up industries of that character that really mean something to the State and its community, than, possibly, to let it all be wasted in the manufacture of carbon black? This glass factory uses ten times less gas than the carbon plant and it employs 15 times more people than the carbon plant, and, therefore, it would seem to me that it would be of interest to reserve something of this great supply that we have, which is not inexhaustible, to build up the industries of the State. But more than that, I believe that gas should be used, as far as possible, for domestic consumption and domestic use, because there is no asset, no natural asset that means more to the people than natural gas.

The City of Shreveport, which has 40,000 people, I question if it has five tons of coal in that community. It is supplied altogether by natural gas, in all of its domestic and industrial ac-

tivities. The people are supplied with natural gas at about 25 cents per thousand. The industries are supplied with gas, I think, at 10 cents, or possibly 12 cents per thousand cubic feet. The town has spent many hundreds of thousands of dollars in equipping itself for the use of natural gas. Have we the right to permit a carbon plant or a dozen carbon plants to be erected in that district and use up the supply of gas that naturally belongs to that community, for the upbuilding of selfish interests against the general community interests? I take it that we have not. I take it that this great resource of this section should be protected as far as possible for the general use. I also take it that conservation does not mean hoarding. I believe that this asset should be put to a legitimate use. I believe that in the districts where there is no other use for the gas or no immediate use for it, that it should be used for the manufacture of carbon, or any other industries of a character that would use this gas, but in great centers, where there is a large community interest, I believe that that interest should be protected.

The State, at its last session of the Legislature, granted to the Department of Conservation, through its Commissioner, the right to govern these conditions.

I have required that every gas well in the State be metered, and I have required that not more than 25 per cent of the potential capacity of these wells be used, and I have also put in another rule that a plant coming into the State of Louisiana for the purpose of manufacturing carbon out of gas should first furnish the Department of Conservation specifications, and that they must be required to get a permit from the Department of Conservation to operate; that further, no gas should be used in the manufacture of carbon until the gasoline content has first been taken from it, that is, where it could be taken profitably. Some of the gas we have has not enough of the gasoline content in it to be profitable. Some of the gas is yielding all the way from 100 to 160 barrels of gasoline to the million cubic feet of gas, and, therefore, it is profitable in those plants where the gas is rich in gasoline content, and they are required to first extract the gasoline before using the gas.

Now, we have done that with a full knowledge of the fact that it will probably prevent industries of this character from coming into the State. I have just granted a permit to one to-day to come into the State, but I believe it will deter a good many industries of this character from coming into the State, and, candidly speaking, gentlemen, I hope it will.

The time is not ripe to refuse permits, but we are going to be very guarded in this, as we do not want to place ourselves in the condition that other states of the Union have in letting this wonderful asset slip away from us and being all burned up in the making of carbon black, and that is one of the points that I wanted to stress particularly, because it is a question that interests us deeply, and we think our position in the matter is entirely correct.

SEWAGE WATER PURIFICATION AND DRAINAGE IN NEW ORLEANS

By G. G. EARL

Chief Engineer and Superintendent of Sewerage and Water Board

Read at the New Orleans Meeting, December 6, 1920

Going away back to 1878, the last great epidemic of yellow fever in New Orleans, this city followed that by adopting at that time the belief that sewerage would be the salvation of the city in connection with yellow fever, and gave at that time, in the early eighties, a franchise for the construction of a sewerage system. That, however, fell through. There was nothing done in regard to it. And again, in about 1891 a franchise was given to a private company to construct a sewerage system, that being the same idea at that time. That franchise was given and plans were developed for a sewerage system and work started, but as a private enterprise, a sewerage proposition is a pretty hard one to carry through, and they failed financially, facing the great difficulty in the construction of the work and the lack of faith of the people in the proposition, and also a good deal of hostile public sentiment against private ownership of a sewerage system.

In the meantime, so far as the drainage of the city was concerned, they had a very small pumping capacity, which gave very inadequate drainage, with only surface gutters running to canals to the rear of the city, which were always full of water, so that there was no drying out of the soil.

While the city of New Orleans was saturated through the surface, practically, the gutters were always filled with standing water in them and were very objectionable.

In the meantime, the water supply of the city was the Mississippi River, which contains about a cart-load of mud on an average, per million gallons of water.

There had been an effort in 1892 to filter the water, but that effort had proved unsuccessful. They attempted to filter the water just as it came from the river, without any preliminary treatment, and found that frequently they could not filter enough water

to wash their filters, so that, all told, up to 1900, the city had made no progress in any one of those three particulars. They had succeeded in keeping yellow fever out by rigid quarantine, and there was no yellow fever in New Orleans from 1878 until 1897, when it broke through the quarantine around by way of the Gulf Coast, in through the river points.

And there was a motion towards drainage in 1895 when very elaborate and wise plans were prepared and the work, in 1897, was started of building a drainage system, but inadequately financed.

Following 1897 there was a light epidemic of yellow fever in 1897, 1898 and 1899—very little, but enough to do a tremendous amount of damage through quarantines, so as to very greatly embarrass the business enterprises of the city, and again the belief was conceived that the only way to eradicate yellow fever was by an adequate sewerage system, and by 1899, the citizens got together, and eventually arranged a preliminary scheme for financing of sewerage, water and drainage, and passed a law and voted a tax for the construction of the three systems, the finances being rather inadequate, and the necessity to conserve resources and make every dollar count as far as possible in service being very strongly before us at all times, so that up to 1900, the city had barely started its drainage work and had made no improvement on either the sewerage or water situations. All premises in the city of New Orleans up to that time had either a vault or a cesspool. There were no underground sewers, no underground drains. The only water supply of the city was the Mississippi water, unfiltered, and only about 5,000 premises out of perhaps 65,000 at that time were equipped even with the water works system, the balance of them depending entirely upon water brought from rains on the roofs and stored in wooden tanks above ground, which we termed cisterns.

Up to the end of 1900, the death rate of New Orleans had averaged between 28 and 27 per thousand, the total death rate. In 1900, the first start of the drainage went into operation, and although it was less than half of its present pumping capacity—not over a third of its present pumping capacity—it did, for the first time, begin to lower ground water levels, and immediately following that the death rate commenced to go down, and the death rate of the city has decreased until now, with the gradual improvement in sewerage and the drainage conditions, the greater drying out of the soil, it has gradually decreased until last year it was

below 19 per thousand, that being a saving of about 32 hundred lives a year based on the present population, and a matter of difference in the average duration of life of 16 years.

All told the city has spent in the construction of the sewerage and water and drainage systems, approximately 30 million dollars to date, or, including sub-surface drainage built by the people at the expense of the property owners and not included in the tax, a little over 32 million dollars.

The cost to-day of maintaining and operating these systems is probably in the neighborhood of $1,400,000 per year for the three systems, and the main factor in this work is that we have laid the foundation upon which the city has built up a sanitary reputation which is pretty good, and which has decreased the death rate equal to an average increase of sixteen years in the life of the citizens of the city.

THE TREATMENT OF SEWAGE BY AERATION IN THE PRESENCE OF ACTIVATED SLUDGE. IV

By EDWARD BARTOW

Read at the New Orleans Meeting, December 7, 1920

In the last paper on this subject "III" read at the Buffalo meeting in June, 1917,[1] a summary of the work already done on this method of sewage disposal was given, followed by a description of the continuous flow plant that had been operated at the sewage testing station of the State Water Survey Division at Urbana, Illinois. Different types of air diffusers had been tested with the conclusion that filtros plates were the best available at that time. A trial of a rotary filter furnished by the Koering Manufacturing Company had not proven satisfactory. Later experiments with this filter have confirmed the first results. Sludge dewatering with a centrifugal machine had given promising results. Owing to the war and to the fact that many of the Water Survey staff entered the service, work at the station was practically suspended till early in 1920.

It has been generally admitted that the success of the process will depend on a reduction in the amount and cost of compressed air used, and in the development of a successful method of dewatering and drying the sludge in order that it may be made available for use as a fertilizer.

It will be impossible to give you the complete story of the progress being made in accomplishing these two results, for a second edition of the Bibliography of Activated Sludge, being prepared by J. Edward Porter for the General Filtration Company, will contain more than 600 titles.

In 1916 George T. Hammond prepared a very complete history of the activated sludge process. He described the work that had been done throughout the country. Shortly after that time, owing to war conditions, the experiments diminished to a considerable extent. A large number of additional articles have appeared recently.

[1] *Transactions*, 10, 159.

In 1919 I had an opportunity to visit some of the installations in England and in this country, including what I believe to be the largest and best plants. Through the courtesy of J. C. McVey, chief engineer of the city of Houston, I am able to give some up-to-date information concerning the plants of that city. They are

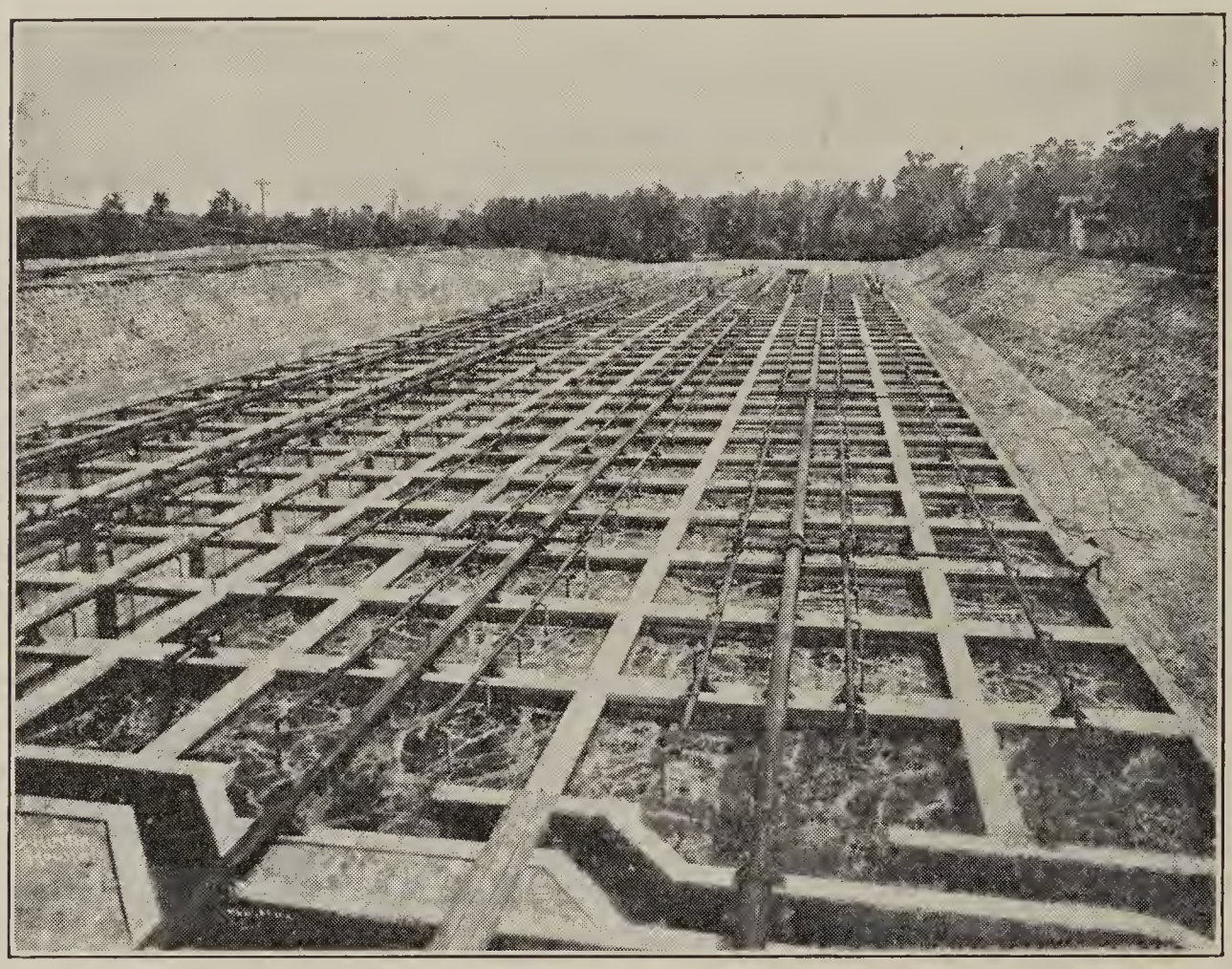


FIG. 1. Aerating tanks, Activated Sludge Plant, Houston, Texas.

the largest in this country and also in the world that have been in successful operation. The larger plant consists of aeration chambers (Fig. 1), settling tanks (Fig. 2) and large air compressors in a building at one end of the tanks. On the hill above the plant are buildings in which sludge-pressing and sludge-drying experiments are being made (Fig. 3). This plant has been described more in detail elsewhere (Fig. 4). Suffice it to say that a very satisfactory effluent has been obtained. The sludge has been disposed of by lagooning and up to the time of the presentation of this paper the methods for dewatering and drying the sludge have not been perfected.

The first plant of any size was built at Manchester, England, in 1914 and has been in operation since that time (Fig. 5). It is

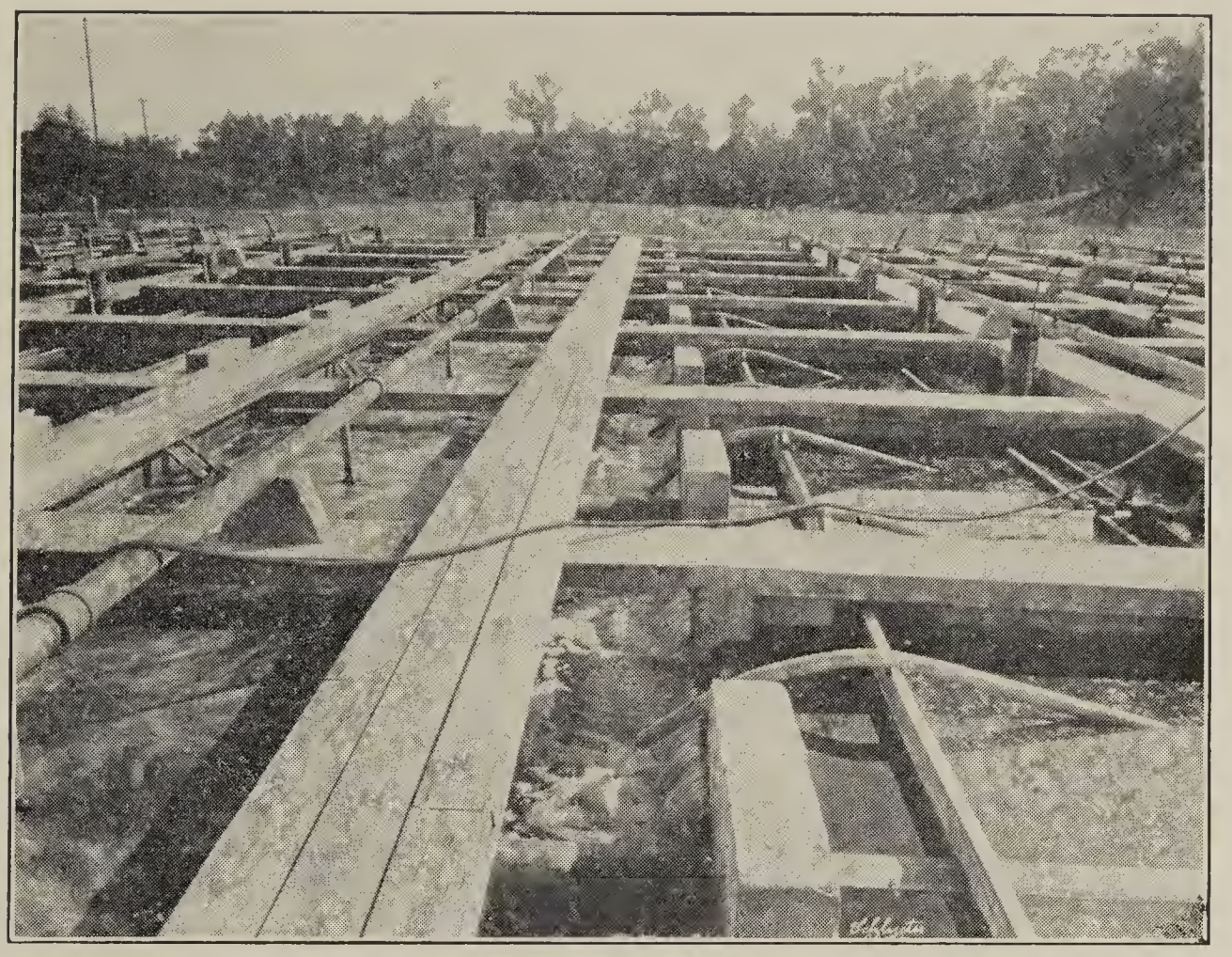


FIG. 2. Settling tanks, Activated Sludge Plant, Houston, Texas.

FIG. 3. General view Activated Sludge Plant, Houston, Texas.

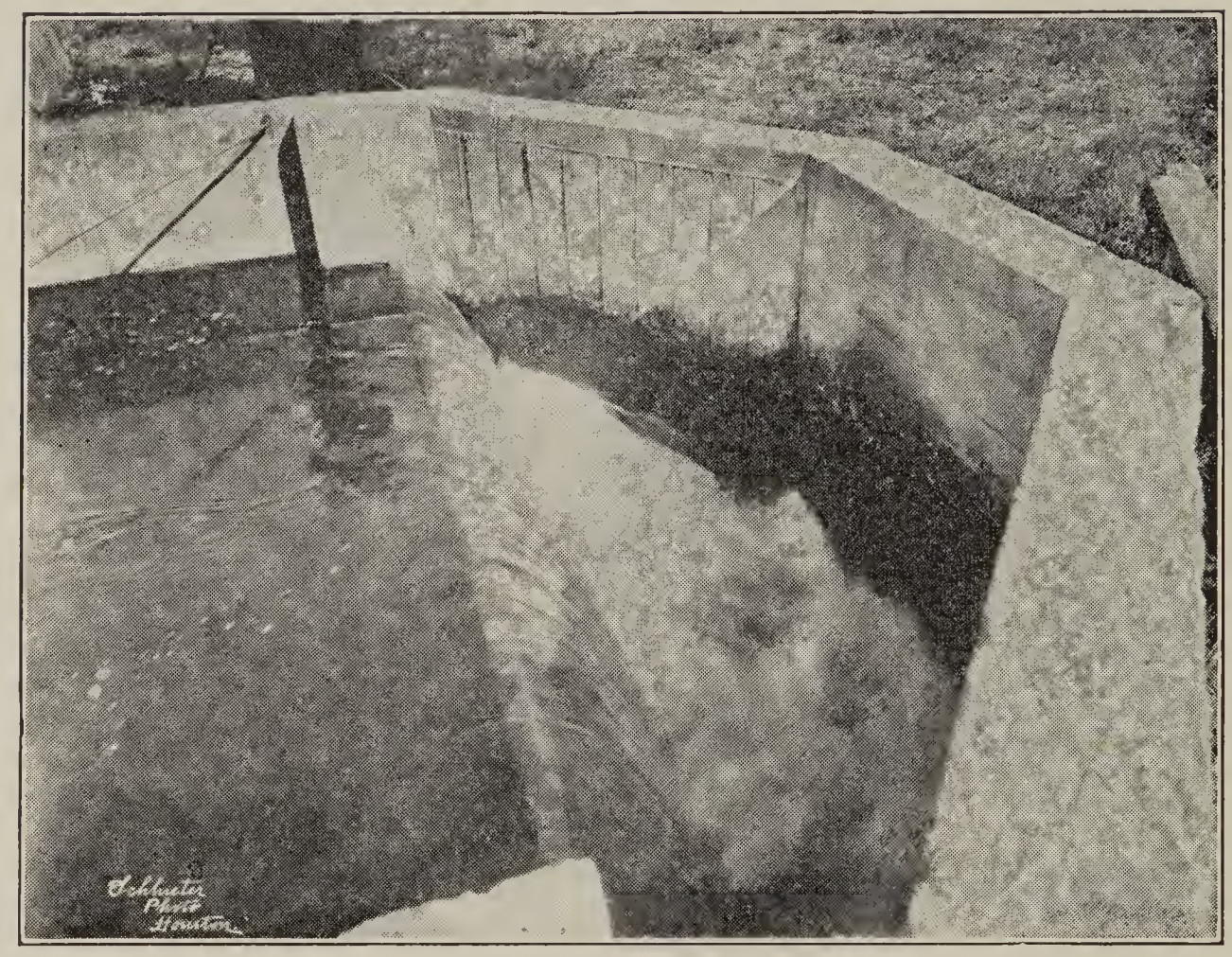


FIG. 4. Main Outfall Weir, Activated Sludge Plant, Houston, Texas.

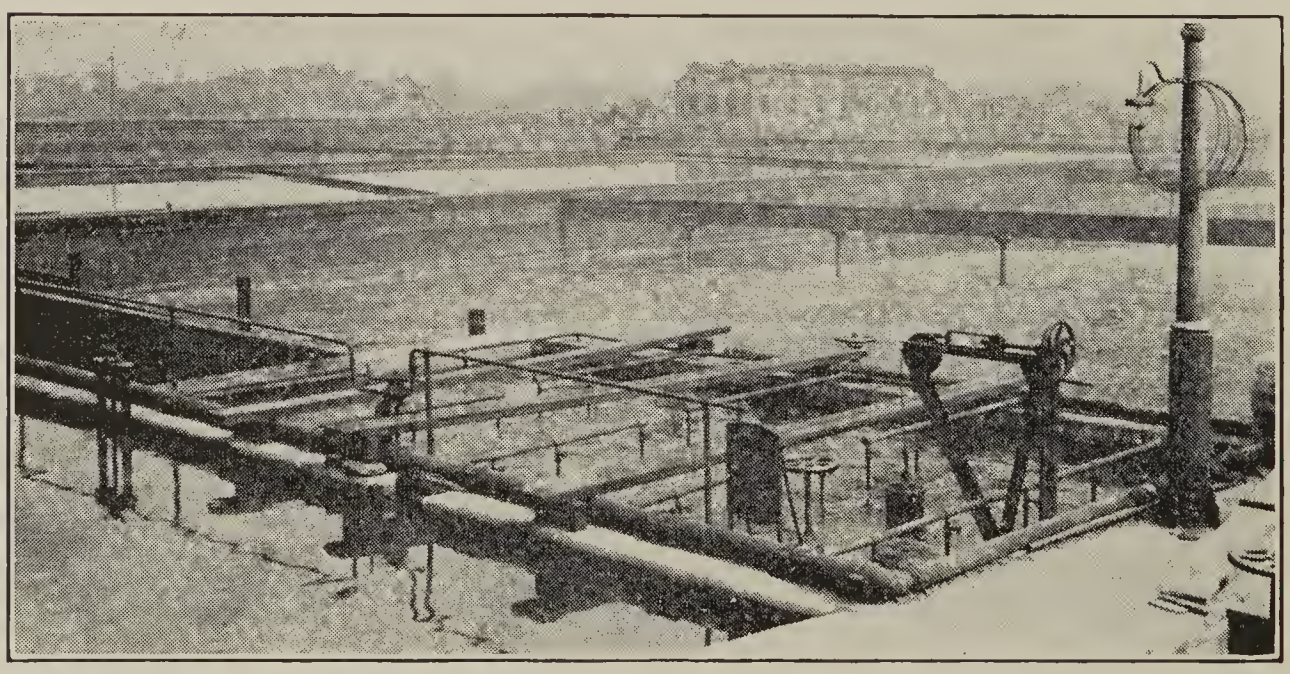


FIG. 5. Original Activated Sludge Plant, Davyhulme Works, Manchester, England.

operated on the fill and draw system and has a daily capacity of about 50,000 gallons. It was built in one corner of the settling tanks used in the sewage disposal system of the city. As a result of the experiments with the fill and draw system, the city of Manchester, Rivers Department, constructed a plant on the continuous flow plan at the Withington works, having a capacity of about 500,000 gallons daily (Fig. 6). In this plant the sewage passes five

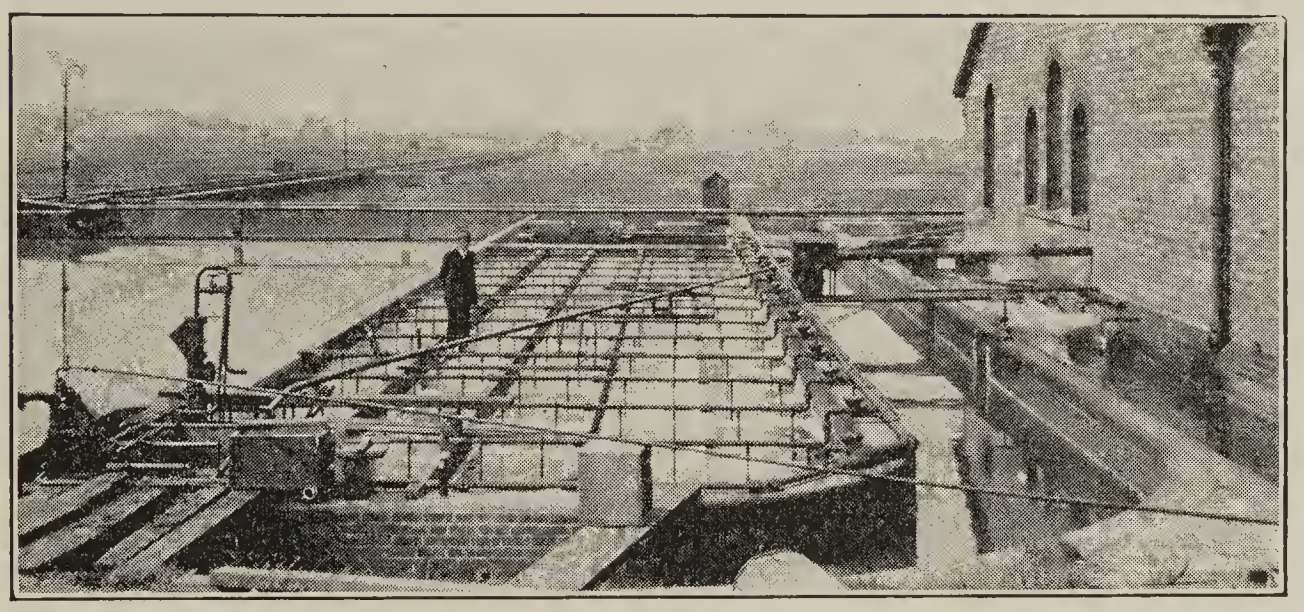


Fig. 6. Activated Sludge Plant, Withington works, Manchester, England.

times the length of the tanks and the sludge is returned through a pipe to the point where the sewage enters the tank. The mixed sewage and sludge passes to the center of the settling basin and the clear effluent flows out over the edges of the tank at the corners in order to prevent short circuiting. The results obtained at the plant at the Withington works have been so satisfactory that a much larger plant has been constructed at the Davyhulme works. The sewage and sludge in this case will pass three times the length of the plant and the sludge will be returned to the entrance in an open channel of half the width of the aerating channel. For experimental purposes, two kinds of settling tanks have been constructed. One for gravity separation having a sharply sloped bottom so that the sludge may settle to the center of pyramids and be removed by gravity. The other having a circular bottom sloping only slightly and so planned that the collecting mechanism will carry the sludge to the center to be removed from that point.

The activated sludge plants at Manchester have been the largest and most successful in England. A description of this plant may be found in the reports of the Rivers Department of the city of Manchester.

The plant at Worcester (Fig. 7), which is adapted from former purification tanks, has also been successful and it is said that the activated sludge process will be adopted for the treatment of all of the sewage from the city of Worcester.

FIG. 7. Aeration Tanks of Activated Sludge Plant, Worcester, England.

During the war, several small plants were constructed at hospitals and munition plants. One at Blackpool takes care of the sewage from a munitions plant, employing 3,000 men. This plant was cared for by regular employees of the plant in connection with or in addition to their other duties so that the expense for labor at the small plant was almost negligible.

In the United States, aside from the plants at Houston, most of the activated sludge plants are experimental. The experiments which have been made by the city of Milwaukee and by the Sanitary District of Chicago have led to the adoption of the process for much larger plants. The Sanitary District of Chicago has a large unit under construction at Maywood. A large plant will ultimately be built to dispose of the waste from the stock yards and one will be constructed in the Calumet district. Experimental work is being carried on with the disposal of wastes from stock yards, tanneries and from a starch factory.

At Milwaukee preliminary experiments have been completed and at the present time they are especially interested in settling the problem of sludge drying in order to determine the proper designs to adopt in their large scale treatment plant.

The State Water Survey Division at Urbana with a small appropriation has established an experiment station which is being put in operation. In this it is proposed to have a plant as complete as possible. It will have approximately 100,000 gallons daily capacity and will include screening, aeration, sludge dewatering and drying. The sewage flows by gravity through the grit chamber (Fig. 8) to a screen

FIG. 8. Grit chamber and screen at Experimental Plant, Urbana, Illinois.

furnished by the Dorr Company of New York. After screening, the sewage passes to the pump pit from which the screened sewage is pumped to the aeration tanks. By use of screened sewage trouble from stoppage, which often occurs when unscreened sewage is to be handled, is avoided. The activated sludge plant itself (Figs. 9–10) contains 2 tanks 17 feet in diameter and 13 feet in depth. The sewage may pass through in series or in parallel. It is expected to use the plant in a manner similar to that used by the Dorr Company, in an experimental plant at Mount Vernon, N. Y.

About half way between the top and bottom of the tank is a tray inclined slightly upward toward the center. Air is forced in through filtros plates at the bottom and is caught and carried to the center of the tank under the tray. The air rises through the central well and is returned with the incoming sewage through another well to the lower compartment of the tank where it is carried by a revolving mechanism to the outside toward the outer rim of the bottom of the tank where it passes over the plates and is caught up by the air and carried with the air to the top thus completing the circuit.

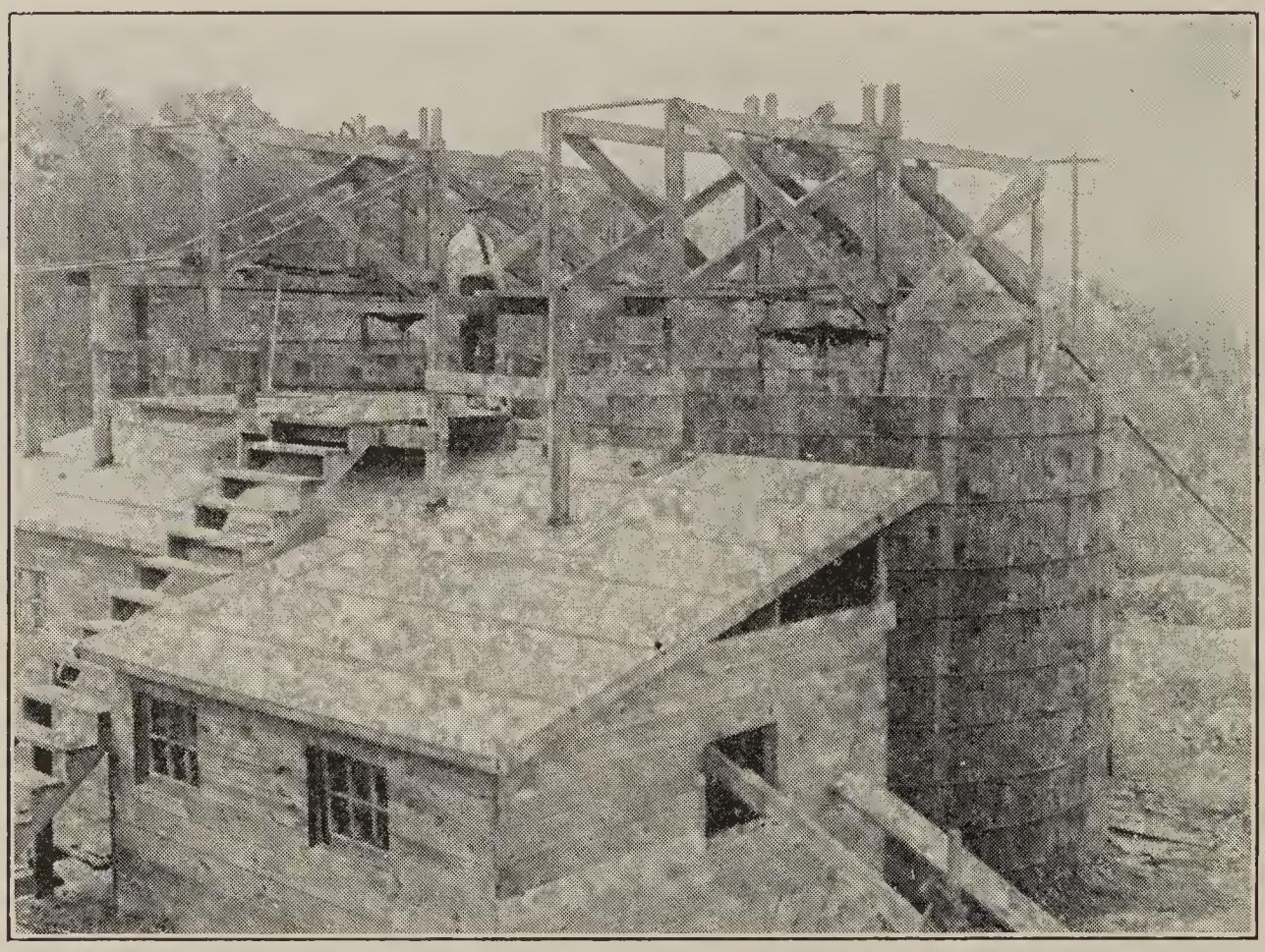


FIG. 9. House for compressor and pump, Experimental Plant, Urbana, Illinois.

At the top, part of the mixed sewage and sludge passes over an adjustable collar into the upper part of the tank which is a settling compartment. The clarified liquid passes over the outer edge into the trough from which it passes to a second tank or to a stream. The sludge is carried by another mechanism to the outside of the upper chamber and flows by gravity through down cast peripheral wells into the lower chamber where it is mixed with sewage and air and enters the aeration circuit.

We thus have two circuits; one for sewage, sludge and air and the other through the sedimentation section of the tank for the sludge alone.

It is hoped by this method to demonstrate what was shown by the Mount Vernon test, that the amount of air used can be greatly reduced.

The two important problems of the activated sludge process which have not been satisfactorily solved are the amount of air used and the drying of the sludge. By the Dorr Peck process, it is proposed to reduce the amount of air. Two other proposed methods should be mentioned, both English. In one it is proposed to use the air intermittently. Sufficient air will be added to satu-

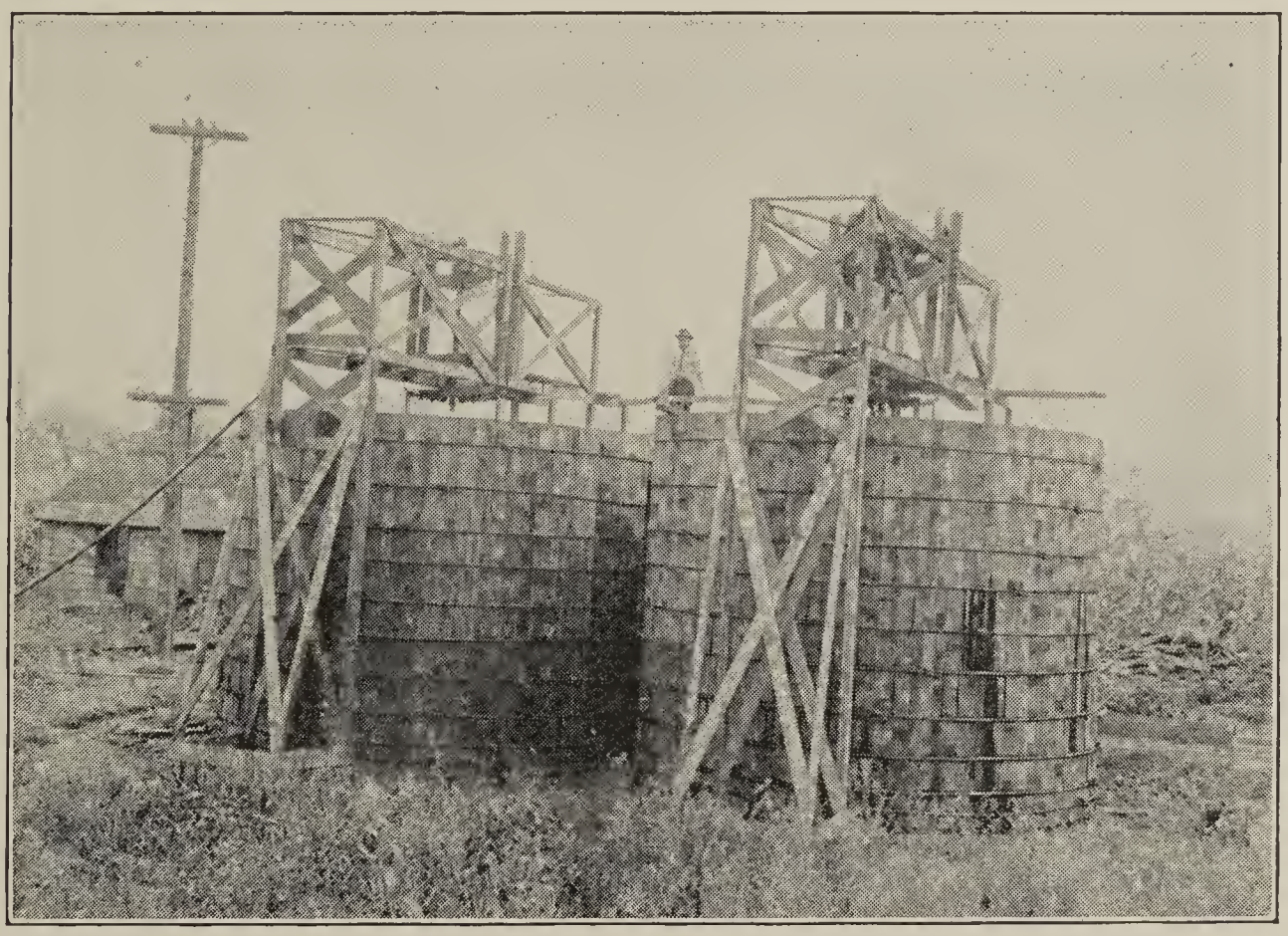


FIG. 10. Tanks, Activated Sludge Plant, Dorr-Peck Process at Experimental Plant, Urbana, Illinois.

rate the mixture of sewage and sludge, then the addition of air is discontinued for a while until the air is used up. In the other, the scheme which has been adopted for the new plant at Manchester, the air comes in at one side of the long tank and is expected to cause the sewage and sludge to circulate in a direction perpendicular to the line of flow through the tank. The portions of the tank at the sides farthest from the aerating plates have a curved bottom and it is expected that the circulation will be such that the amount of air required will be greatly reduced.

The other problem not satisfactorily solved is sludge drying and

it is my thought that many cities which have been considering methods of sewage disposal have hesitated to adopt the activated sludge process because of the difficulty in disposing of the sludge. Because of the expense, engineers have advised against its adoption by several cities. Where possible, if the amount of air could be decreased and the sludge satisfactorily disposed of, the method might be found the most satisfactory and the cheapest.

At Milwaukee the Sewerage Commission has spent a great deal of time and energy in an attempt to solve the sludge-disposal problem. At the present time they have installed and are testing a continuous centrifugal machine and it is sincerely hoped that it may prove satisfactory and successful. Aside from the centrifugal machine, plate pressing seems to be most promising.

For the final drying, aside from attempts to dry the sludge on sand beds, most attempts have been made by direct heat driers. Recently, the Bayley Manufacturing Company in Milwaukee has designed an indirect heat drier which is to be tried at the sewage testing station at Urbana. In preliminary tests with this drier, a sludge with less than 10 per cent moisture was obtained from the sludge having originally nearly 90 per cent of moisture. There was no unpleasant odor and no dust noted during the process. Drying without odor or dust has not been accomplished with direct heat driers and it is hoped that the expense of the indirect heat driers will not be too great and that it may solve the problem of sludge drying.

In closing I wish to place a final emphasis on what seems to me to be two important problems in the activated sludge process at the present time, namely, reduction of air and the drying of the sludge, with the hope that the problems may soon be solved.

REPORT OF COMMITTEE ON CHEMICAL ENGINEERING EDUCATION

Read at the Detroit Meeting, June 20, 1920

DR. ARTHUR D. LITTLE: Mr. President and Gentlemen, the committee has no formal report to make for the reason that the amount of data which has been collected is so extremely voluminous that a great deal of time must obviously be spent in digesting it before any one is justified in drawing conclusions. But the committee has, after correspondence with some 78 presidents and heads of departments in some 78 institutions, tabulated the courses in all of those institutions, and has given in that tabulation the number of clock hours and the number of credit hours given to each subject.

That tabulation has been printed by *Chemical and Metallurgical Engineering*[1] and copies are available for all of you. There is a great deal of data, as you will observe, which requires consideration, and the committee hopes that each of you will take this tabulation and give some considerable thought to it, and afterwards communicate with the Chairman and give me any suggestions which you may have to make.

There is one outstanding thing at once, and that is the enormous number of subjects which are taught in one or the other of the institutions offering chemical engineering courses. There are something like 235 different subjects included in one or the other, even down to—or up to—Irish history. It is obvious that it is impossible to train men adequately and cover any such amount of ground. Also, you will note as you review the tabulation that extraordinary differences in weighting occur as regards the different subjects. Some institutions give twice or three times or ten times as much time to a particular subject as some of the others. All of those methods of dealing with it can hardly be right, and it seems obvious to me at least that there is a very great need for a standardization of the courses in chemical engineering, if our men are going to meet the demands that the industry and the profession make upon them. So that what the committee offers now is merely a report of progress, in the collection of data which we hope will serve as a basis of some real live discussion, and that out of that

[1] Issue of June 15, 1921.

discussion it may be possible to evolve some constructive recommendations which may be presented to the institutions offering chemical engineering courses, and in the hope that it may be possible to standardize them and add to the effectiveness of the training which they give. In order to facilitate somewhat the consideration of the matter we have tabulated the courses in ten institutions which we thought might fairly be taken as representative. In that, there is a good deal more agreement, although still a surprisingly wide divergence, in the amount of time given to the different subjects. One interesting feature is the very large number of courses or subjects which are dropped in all of these ten institutions. That would perhaps seem to give us a starting point, because unquestionably a very considerable amount of elimination is necessary. This one from Dr. McKee:

"Columbia University in the City of New York. Department of Chemical Engineering. May 26, 1921.

"Committee on Chemical Engineering Education. Attention Dr. A. D. Little.

"*My dear Dr. Little:*

"Some days since I received the tabulated data obtained from the study of catalogs giving courses in Chemical Engineering. It is obvious in many cases that courses are included, due not to their educational value but to some ephemeral situation.

"It must be recognized that in addition to the customary four-year undergraduate course leading to the degree of Bachelor of Science in Chemical Engineering, there is increasing interest in the five-year course such as is given at the Institute of Technology and at the University of Minnesota, and the six or seven-year course as given at Columbia University.

"There is growing recognition of the desirability and even the necessity of making the course in general inorganic chemistry a more intense one than it is in many institutions, that is, this course should be one of minimum of three hours class room and five hours in the laboratory a week for a year; also that qualitative analysis time can be reduced to a low figure or perhaps entirely eliminated. Qualitative analysis is poor training for the student."

I am sorry to have to disagree with my friend McKee in regard to that, because I regard qualitative analysis a particularly good type of training.

"It is also being generally recognized that closer correlation of universities with the industries is much to be desired.

"I believe it is equally important, though not so well recognized, that specialized instruction should be developed in the various institutions, the fields generally depending on the environment of the institution. This policy of specialized instruction is one which was recommended by the councilors of the New York Section of the American Chemical Society to the Council of that society at its meeting in December, 1918. This policy of an institution giving special attention to some one or two industries has been in operation in a few of our universities and with great success, *e.g.*, University of Louisana, sugar; University of Maine, pulp and paper; University of Illinois, coal and ceramics; Cornell University, gas engineering (largely mechanical engineering); University of Washington, wood distillation. From reports obtained it is apparently true that young men who have their interest in a definite field and whose illustrative material is drawn from a single industry, are on the whole better trained than men given an equal amount of instruction in which the material under discussion is scattered over a considerable number of industries. These students, by reason of this specialized instruction, have become intimately acquainted with the problems of a single industry and apparently are even better able to attack the problems of a second industry than if they had had a general training covering many industries including a few days on this second industry.

"Our students are criticized, and justly, as often having but a superficial training. They have not been trained to get to the heart of things. It is only where they have been taught to get to the heart of things by either a training in a specialized industry, or by carrying through a real research problem that they will be able to be of most use to an industry.

"It seems also as if this would aid in working toward a self-contained state and country by emphasizing and developing those industries which have special importance. Furthermore, the indirect effect on these industries wherein the instructor becomes a specialist and consultant in the field of this industry, will be of great value to the educational institution itself as well as to that industry.

"Very truly yours,

"(Signed) RALPH H. MCKEE."

Also the letter of Herbert H. Dow, of Michigan.

"The Dow Chemical Company, Midland, Michigan, U.S.A., April 8th, 1921.

"DR. A. D. LITTLE, Chairman,

"Committee on Chemical Engineering Education,

"Cambridge, Mass.

"*Dear Dr. Little:*

"As a member of your Committee I am expressing my viewpoint as follows:

"It seems a great mistake for a boy to attempt to do stunts in arithmetic that can be quickly and easily solved by algebra. In a similar way, logarithms and trigonometry should be taught before difficult problems in algebra are required. The average engineer does not fully grasp analytical geometry and calculus but can readily learn to solve all calculus problems by suitable plotting on squared paper. I once asked Dr. W. W. Morley, who is unquestionably a great scientist, why people used calculus when they could solve the same problem on squared paper, and be sure they had made no mistakes. He replied that for the average person squared paper was altogether preferable; that he himself used it for all calculus problems, but that for a real mathematician it would be a matter of entire indifference which method was used. However, an error on squared paper is obvious and is not liable to be made, whereas an error in calculus is very liable to creep in unless one is especially gifted along this line or makes almost a life study of the subject. So far as I know, there is no American text book that teaches the solving of calculus problems by graphical methods. I think there is such a book published in England, although it does not appear to cover the subject in a way that would make it suitable as a university text book.

"Years ago the whole field of science and engineering was covered by the two subjects of Physics and Chemistry. In fact, some of the older Natural Philosophies included the subject of Chemistry. It is inevitable, as Science progresses and specialization takes place, that the number of engineering branches shall increase. Mechanical Engineering and Civil Engineering were among the first subdivisions of the subject of Physics to command independent recognition. In the same way, Chemical Engineering should be a subdivision of the general subject of Chemistry, although it might

almost as properly be a subdivision of the general subject of Physics. Later, the great developments in electricity called for a subdivision of Electrical Engineering; in a similar way Mining Engineering became an important subject; and it is quite likely that Chemical Engineering will also call for subdivisions. Developments would seem to justify the general headings of Metallurgical Engineer and Electrochemical Engineer, and Organic Chemical Engineer might become a later development.

"In order to make the subject of Chemical Engineering as great and valuable as possible, it must contain within itself the germs of growth and development. No method of education that will facilitate the acquiring of new ideas has yet been fully worked out. The study of books and of language facilitates the getting of ideas from others but does not develop the initiative and inventive faculty which is essential to progress. The Chinese have remarkable capacity to acquire information from others, but initiative is lacking.

"I think that graphical calculus as above outlined, original propositions in geometry, with the proper amount of shop and laboratory work, would seem to be some help in enabling a student to acquire initiative.

"I believe Dr. W. R. Whitney, of the General Electric Company, Schenectady, has probably had more experience than anyone else in America along the line of the type of training that will develop initiative or the inventive faculties, and his opinion should prove very valuable.

"Dr. Mortimer E. Cooley, Dean of the Engineering Department, and Professor A. H. White, head of the Chemical Engineering Department, University of Michigan, have had wide practical experience, and have developed a course of Chemical Engineering that has turned out men whom we know by experience are very capable. Therefore, their curriculm should be an important guide.

"We have twenty-seven universities and technical schools represented by our employees, but the man himself is so much more important than the curriculum that it is impossible for us to draw any conclusions as to the proper course of training from these men in our employ.

"Yours very truly,

"(Signed) HERBERT H. DOW."

That is about all there is of importance in the correspondence, but I do desire to read this brief abstract from the address in 1919, of the President of Columbia University:

"The outstanding part that engineering and engineers have played in the war and the large amount of attention given to intensive training of men in technical subjects by both the Army and the Navy have just now directed increased attention to long discussed problems of engineering education. Wherever these problems are seriously and capably discussed, it seems to be agreed that while engineering schools may have turned out well-trained graduates, those graduates have not been on the whole sufficiently well-educated men. Of late, committees of some of the engineering societies have been asking the question: 'Do engineers as a group have the same standing and influence in their communities as men in other professions?' They fear the answer is in the negative, and many allege as the reason that engineers are on the whole not so well-educated as their contemporaries in other professions. However this may be, it is a fact that, coincident with the growing importance of engineers in public life, the requirements of the times are setting broader standards of education for the engineer. For example, a report just issued by the Committee on Development of the Institute of Electrical Engineers and endorsed by the Institute in convention, declares squarely in favor of a six-year coarse in Electrical Engineering, two years of this to be given to the study of the humanities."

I don't want to take up myself any more time, but I am very anxious that the members give some careful thought to the tabulation, which, as you will recognize as soon as you see it, represents an enormous amount of work, and we have also made special tabulations showing the total amount of time, the maximum amount and the average amounts given in the different universities, and I think you will agree with me that it is impossible that any such wide variation in weighting can be best, and that there must be something like a standard.

We feel that the time is ripe for a pretty drastic overhauling of the whole question. The committee would like to know what you think about the Case system for training chemical engineers, as Dr. Whitaker used to employ it in Columbia, and it was employed in the Institute of Technology, and what you think about the method of practice in the Institute of Technology or any other

plan which may occur to you. And with those matters before you, the committee hopes to be able to formulate by the next meeting something which is constructive and helpful. (Applause.)

PRESIDENT WESSON: Gentlemen, I think you are all indebted to Dr. Little for his painstaking work on this whole subject. It is something which concerns all of us very deeply, and the future of our industry, and I sincerely hope that you will all read these tabulations and co-operate with Dr. Little as much as possible. Is there any discussion or motion?

DR. W. P. MASON: May I ask, Dr. Little, with reference to the ten institutions which were referred to. Are they published in the same periodical?

DR. LITTLE: I am sorry to say that they are not, but I have a photostat here on that matter which I shall be glad to show to you. They are to be published later.

SECRETARY OLSEN: Mr. President, I have looked over this very carefully, perhaps more than some of you, because it came to me rather early, and I would like to make two or three remarks which seem to me would clarify some of the points in this table. If you will refer to the general chemistry course in this table, you will find that as low as 26 hours is given to the teaching of general chemistry, and there is a high figure of something over three hundred hours. And you will find the same variations in other courses. Some institutions give little time, some give a very large amount of time. You will find that the Massachusetts Institute of Technology, according to this table, gave no time at all to physical chemistry or to physical chemistry laboratory. Now, we certainly cannot assume that that institution does not teach physical chemistry, and when you stop to think of it I think you will all realize that it is very necessary to teach some physical chemistry if you are going to teach general chemistry. If you are to teach qualitative analysis you must present some of the general principles of physical chemistry. The same is true of quantitative analysis. In the various colleges there is considerable variation of practice, as to how much of a subject like that will be taught under the name of "General Chemistry," or "Qualitative Analysis," or "Quantitative Analysis." Professor McKee says he does not want to teach qualitative analysis at all at Columbia University. That does not mean that the graduates cannot make an analysis, but that they will give that work under some other heading. You cannot take

this tablulation and the number of hours given in this tabulation as the number of hours or the amount of instruction given in any sub-division to any main course. The same thing I think is true under the heading of Mathematics. You will find I think that they teach under the head of Geometry or Calculus or something else, a variety of subjects, and that the significance of a given subject in one school or another is not the same. So if you take elements of chemical engineering or any of the other groups in the chart, you will find that the various subjects and titles given are different in meaning and content at the different schools.

Now, it appears to me that an additional tabulation would bring out an important point if we should sum up and give the total number of hours given to chemistry at a given school, the total number of hours given to physics, the total number of hours given to mathematics, and so on through the various subjects, and that total I believe would show a greater uniformity than the hours given under each of these individual subjects.

There is one other comment I would like to make. There are 270 odd subjects taught in the courses on chemical engineering. That seems an awfully large number of subjects, but it looks to me from the examination of this schedule that in given localities they have taught or offered courses that suit the industry in that locality. In Louisana and the Southern States a great deal of attention is given to sugar chemistry and everything that pertains to it. In the Western States attention is concentrated largely on mining engineering, in the Eastern States on general inorganic work which is carried on, and so these various courses have been adapted to suit each given locality. Most schools will have at least 75 per cent of local attendance. But each of the universities, colleges and technical schools in the United States will serve their locality and will offer courses which suit that particular locality, and I think that accounts for the very large variation in the number of courses.

DR. LITTLE: Mr. Chairman, if I might say a word following Dr. Olsen's remarks: I quite agree with practically all that Dr. Olsen has said. I want to make this clear, however, that the subdivision of the courses which appears by the tabulation is one which the institutions themselves have made, and is not the work of the committee which had decided after studying catalogs for five weeks that we would get into endless difficulty if we made up

the tabulation ourselves. Therefore, we prepared a blank on which we listed subjects scheduled in the different catalogs, and sent those blanks to the presidents of the universities with a request that they transmit them to the heads of departments, and that the head of the department himself be responsible for the way in which it was filled out. I might also say that the tabulations suggested by Dr. Olsen have been made and are available here, not yet in form for printing, and they still show very great variations. For example, taking the 78 institutions in chemistry, the maximum number of hours given to lectures is 1,288, and the minimum hours are 240. The maximum hours of laboratory are 2,124 and the minimum 482, and the average are 650 for lectures and 1,148 for laboratory. The maximum is almost twice the average, and nearly five times the minimum in the case of lectures in chemistry. In physics the maximum is 297½ for lectures, and the minimum is 34. The maximum hours of mathematics are 630, and the minimum 130. Mechanical engineering maximum 1,020, minimum 40. And so on. It appears to be an extreme divertisement which assuredly a mere change in location will not account for.

REPORT OF COMMITTEE ON CHEMICAL ENGINEERING EDUCATION

Read at the New Orleans Meeting, December 6, 1920

November 22, 1920.

Dr. John C. Olsen, Secretary,
American Institute of Chemical Engineers,
Polytechnic Institute,
Brooklyn, New York.

Dear Sir:

For reasons which will be immediately obvious your Committee is not yet in position to do more than render a further report of progress. There are known to your Committee 77 institutions in the country offering courses in chemical engineering. We have made a necessarily elaborate effort to analyze each of these courses and to tabulate for purposes of comparison the required subjects included in each course with the number of hours assigned to each subject in each institution as totalled in the four-year course and in each year thereof. Our survey has already clearly disclosed the crowded

condition of these courses, the bewildering number of subjects which they have attempted to cover, and the great variations in the relative importance attached to the various subjects as shown by the time allotted to them. There is little evidence of anything like a standardized course, and the need for some coordinating and regulating impulse or agency is strikingly apparent.

Your Committee ventures to express the hope that when the data upon which it is now at work are assembled and digested in its final report it may be able to present some constructive suggestions based upon its study of this material which may then serve as a basis for discussion by the members of the Institute leading up to some formal recommendation by the Institute for the reorganization of at least some of these chemical engineering courses and some expression of opinion concerning the relative importance which the Institute attaches to the various elements of these curricula.

At some risk of premature conclusion your Committee even now ventures the opinion that a radical change in the organization of chemical engineering courses and in teaching methods appears to be desirable, if not indeed imperative, but as to whether this will involve a development of the case system of instruction, the development of semi-works laboratories, provision for more direct contact with industrial operation, or some altogether new alternative your Committee is at this time unprepared to say.

The Bureau of Education has noted a recent tendency to lengthen engineering courses, and your Committee notes that nine of the institutions included in its study are now offering five-year courses in chemical engineering, while one university offers a sixth-year course, although it should be noted that in the case last mentioned three of these years are required to be spent in the arts course.

As bearing broadly and yet most directly upon the education of the chemical engineer the attention of the Institute is directed to the article by Sam. A. Lewisohn in The Atlantic Monthly for September, 1920, entitled "Industrial Leadership and the Manager," in which the failure of technical graduates in their industrial relationships is attributed to their lack of interest in the personnel problem and the deduction reached that "the evidence, in fact, is overwhelming that the usual practice in the past of confining the training of the engineer solely to studying the reactions of dead matter has tended to cripple him in his handling of human relations.

A purely technical education in problems which require quantitative methods does not equip a man to assume leadership of men." The remedy, in the opinion of the author, is for trustees and faculties to sacrifice a certain amount of instruction in subjects involving purely physical problems and devote an adequate number of hours to social economics and the modern technique of handling labor. "In order to achieve the desired results," he continues, "there must, in addition to a revision in the formal curricula, be modifications in the practice-work conducted in the summer months, so that the students will supplement their civil engineering, geological expeditions, and other field-work by actually working in industry with the men they will handle in their future careers." Thus far your Committee has discovered only one institution which includes the subject of Industrial Relations as such in its chemical engineering course and only five which seem to treat it under some phase of Industrial Engineering required in the chemical engineering course.

Respectfully submitted,
JOSEPH H. JAMES,
A. D. LITTLE, Chairman.

THE PRESIDENT: Gentlemen, you have heard the report, what is your pleasure?

(A motion that the report be accepted was made and duly seconded and unanimously carried.)

COSTS—A SHORT STUDY OF FACTORY ECONOMICS

By A. G. PETERKIN

Read at the New Orleans Meeting, December 6, 1920

The layman's idea of a cost system is a mechanical routine which month by month turns over to the sales department the cost of each of the materials which it sells. As a matter of fact, it has been attempted in many cases to put this idea into operation. I think it is true that the result has been a compilation of figures which fall under the head of "statistics" in Walter Bagehot's famous expression: "There are lies, damn lies and statistics." The problem which confronts the manager of a factory is not the mechanical grinding out of so-called cost figures, but a study in economics.

What Should a Cost System Do?

In the first place, a cost system should give information to the sales department which will enable its members if possible to sell the production at a profit. The sales department, however, is not able to control the market price of certain commodities, which are set by outside conditions and the selling price of other commodities. For example, if a substitute material is offered, the limitation is imposed that the selling price must have some definite relation to the price of the material substituted. In such cases, given a process of manufacture, the cost system is required to tell the price at which the raw materials must be bought to enable the material to be marketed.

It is of no less importance that the system should tell the factory management and the sales department under just what conditions the costs submitted are possible, and in what way they will be affected by changes in method of manufacture, and by increase in the individual or total volume of production.

The cost system might be required to produce a sense of financial responsibility in the heads of all the various departments, from the top down. This is particularly true of corporations or large businesses where the combination expected to give results is that of "your brains and someone else's money." The repair department,

for instance, should be run as far as it is possible in the same way as a separate business which was furnishing the same service to the plant. The head of every production department will, to my mind, work to better efficiency when it is required of him that he think in terms of dollars and cents as well as in terms of men, pounds and gallons; he should run his department in the same spirit as he would were he using his own money. So far as possible, every man should be required to know how much money he is spending for every item where the discretion he uses in his daily work will influence that amount.

When once reliable cost figures have been established and analyzed, it is more important to obtain information looking toward the control of the expenditures making up the cost than to repeat the calculation of the final figures at frequent intervals to the exclusion of such information. The one method leads to irritating post mortems; the other avoids them. As in sport, so in business, watch your stroke, and let the score take care of itself.

Interdependence of Costs

In setting out to arrive at such results at least one simple principle must be kept in mind. When once a factory has been organized to turn out any given set of products, so far as cost is concerned every one of those products becomes to some extent interdependent. To get a definite cost figure on any one of them, the cost of each one of the others must be fixed at the same time. The more varied and complex the operations of the plant are the truer this is. It is least true in a factory, if such a one exists, where each one of the products is independent of the others so far as labor, raw materials and intermediate materials are concerned. In such a case as that, the interdependence lies mainly in the overhead, and the variation in cost will arise from the difference from time to time in what may be called the degree of saturation of the overhead. When the volume of production which a given organization can turn out is the maximum, the costs will be lowest, and as the volume decreases the cost of each one of the different materials will go up.

This factor of interdependence, however, in the chemical business is influenced much more by another condition than by overhead expense: If the decision is made to manufacture a certain material by a chemical process, one is almost always confronted by the

necessity of producing another or even several others simultaneously. These "byproducts" may or may not be useful and valuable. The growth of the industry has largely been effected by making them so. The two or more products from such a process may have been subjected to exactly the same procedure and no more expense incurred in making one marketable than any of the others; on the other hand one or more of the products may have necessitated a disproportionate expense. Does this extra expense as an item of cost belong to the products directly responsible; or should the total expense be divided equally among the group? Assume for a moment that the expense is allotted as directly as possible among such a group of complementary materials and costs figured on this basis are given to the sales department. What naturally happens? Vigorous selling of the profitable members and an accumulation of the less profitable! Finally of course all have to be disposed of and the net result is a profit or loss on the group. The only rational basis for computing costs, and profit, is on the group considered as a unit. No arbitrary fixing of values within such a group changes the basic fact that the profit is made on the sale of the entire production, although the use of such values may in some cases be a convenient and good method of studying the group profit. Such arbitrary values placed on certain members may not materially affect the cost of the other members, either in amount, in variation or in both. For example, in the manufacture of nitro products, with the attendant production of "spent acid," to figure a cost and profit on the group would merely tend toward confusion. The market value of the "spent acid" can be ascertained with considerable ease; the placing upon it of such a value will throw all the cost and all the profit to the nitro product, and will clearly give the information necessary to a proper manufacturing and sales policy.

Maximum Net Returns on Group of Products

Possibly the best example of this phase of the subject is the case of a factory refining oils. Each crude worked may give some amounts of the same materials and at the same time products peculiar to itself. Each crude, also, can probably be worked up in various ways to produce several sets of products. The attempt to follow each intermediate step in the refining process, to find the cost of the intermediate products and so on to the finished products, results in figures which are valueless in most cases. The question

here is of the proper profit on the group of products from one crude, and the most profitable group to make from that crude. Frequently every finished product has an established market price, and the price which can be paid for the crude has to be determined by taking the difference between the combined market value of the entire production, and the total working cost, freight, profit, etc.

There are many cases where evaluation of individuals is necessary in which the products cannot be evaluated by placing arbitrary values on the minor members, and dividing the remainder of the cost proportionately. A rule capable of fairly general application is to divide this remainder among the major products in the proportion of their market values. The one point which should never be lost sight of, however, is that the manufacturing and selling policy should be governed by the net return on the group.

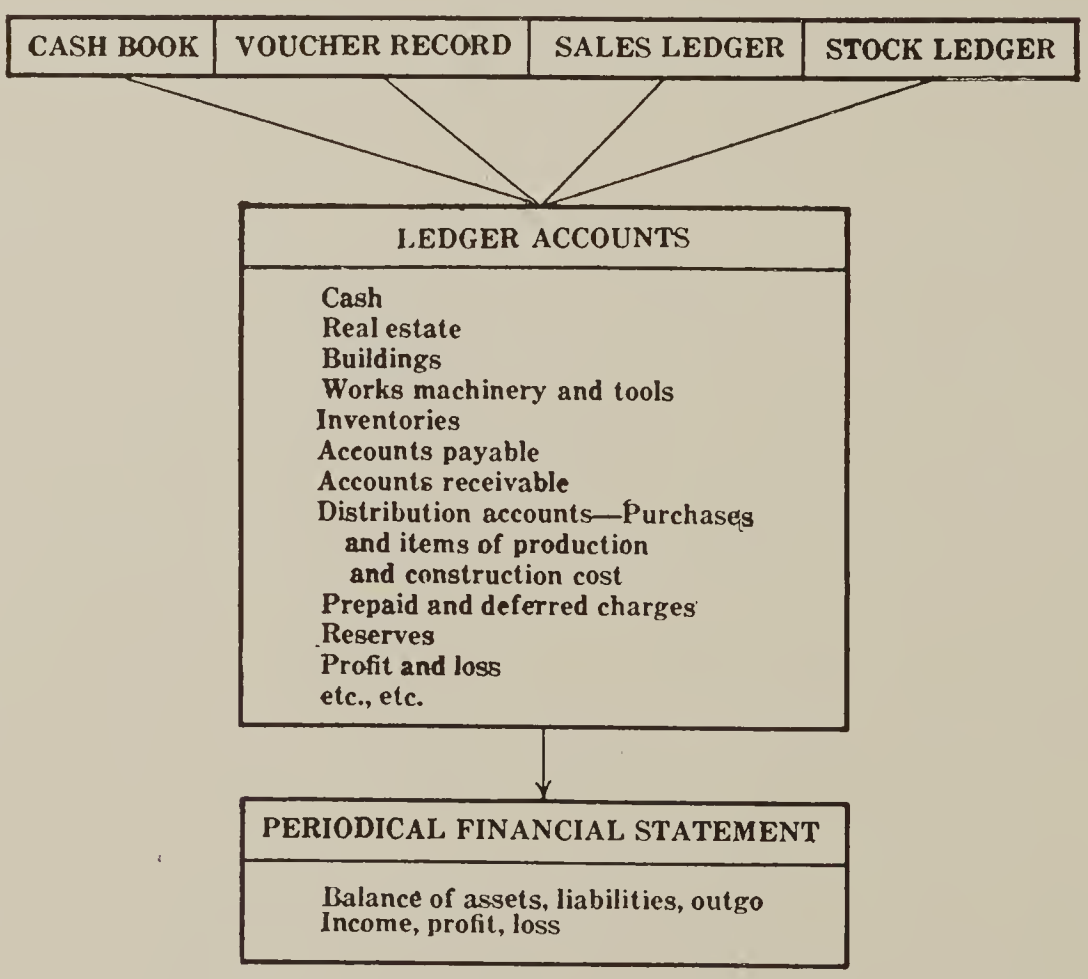
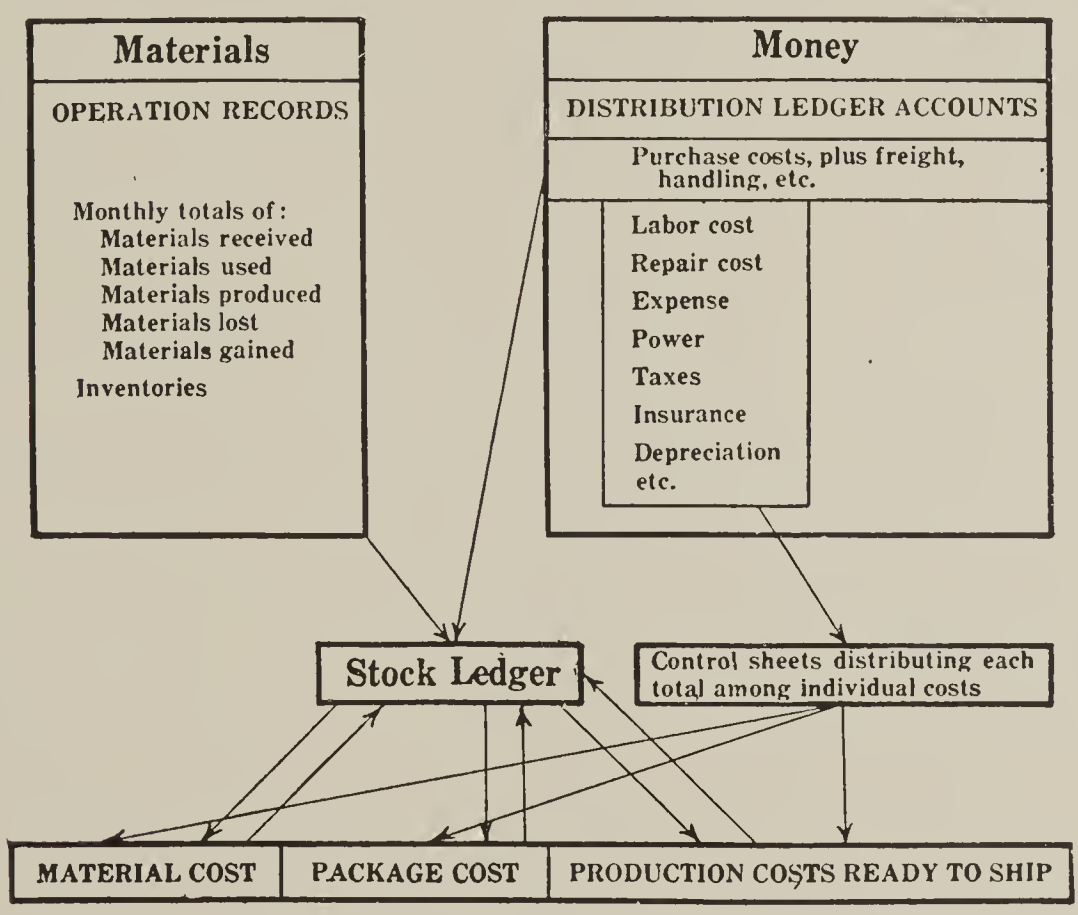


FIG. 1

Another phase of the same problem is the question of the price at which a finished product from one process shall be charged as a crude to another. If such a material be marketable in the maximum volume possible to produce, it might well go into the subsequent process at its market price, since the only justification for the ex-

pense of further fabrication is a profit greater than can be obtained by its sale. The first process must then be given the credit for the profit which would have accrued had the sale taken place. If the object of further processing is to take care of an otherwise unmarketable excess, the same reasoning would lead to its being charged in as a crude at not more than actual cost.

Before going into the details of the actual work of a cost department, the relation between the bookkeeping and the cost systems should be clear. Fig. 1 shows the layout of the former; Fig. 2, that of the latter.



COST OF GOODS SOLD
SELLING AND ADMINISTRATION COSTS
TOTAL COST
SALES VALUE
NET PROFIT

FIG. 2

DISTRIBUTION OF LEDGER TOTALS

The cost system is not an essential part of the bookkeeping system; it is an analysis of the bulk cost of the operations carried

out; it does not even furnish, necessarily, the value of each item of the inventory. Of course, in possibly the majority of cases, the individual inventory items are placed on the books at a value figured out by means of a more or less mechanical system, but exceptions always have to be made where such a value bears no relation to the actual market value of the material. It is an unfortunate fact that occasionally materials are manufactured at a cost which is greater than the market value, and the inventory based on such a cost would certainly be inflated by at least the difference between the two values.

To go now to the methods to be employed in compiling plant statistics, and to the finished form they shall take:

The direct charges to any product or group of products, for superintendence, labor, repair, materials, etc., are calculated by distributing the ledger totals for these items by means of the usual code system, using report blanks for record of labor-hours, etc., placed in the hands of the foremen or workmen as may be judged best.

The question of the method to be used in assigning indirect charges, superintendence and various expenses covering several departments, the plant burden, etc., is a vexed one. So far as possible, each one of the items going into any such general expense account should be spread over the products necessitating it on a logical basis applying to the individual item alone. The cost of the control laboratory, for example, can as a rule be split up and charged to the products involved, on the basis of the actual cost of the tests made for each one. Such few items as cannot be treated in this way—for example, office expense or general management—have necessarily to be grouped together and prorated on an arbitrary basis. The basis most generally used is that of "productive" labor; the products are charged with their quota of expense calculated from their proportion of the direct labor in the plant. Such a general method, of course, cannot give even an approximation of the truth, unless the labor entailed in each of the group of processes employed in the plant depends on the volume of production rather than the kind. It is obviously true that some processes requiring but little labor consume an altogether disproportionate amount of the expense of superintendence, development, etc. The "punishment must be made to fit the crime," and no rule for such prorating of overhead capable of general application can be laid down.

In general, I believe it is true that yield is the most important item of cost in the chemical industry. The first essential, therefore, in any "chemical" cost system is the obtaining from the factory of accurate figures representing the operations carried out. For that reason I shall go in detail into one method which attempts to do this in a manner which leaves no figures to the imagination.

In order to follow the path of raw materials through a process all the way from the purchase of the crudes to the output of the refined materials, it is necessary to check the weight, or volume, or both, as it is received into the plant; to check the losses or discrepancies caused by errors of measurement as it passes from one part of the plant to another and into the actual apparatus where the process is carried out; to record the amounts of materials produced, both in intermediate stages and in the containers on the railroad ready for shipment to the customers; and to record the amounts of materials in process and in stock at the inventory period. It is important that the means employed to do this should enable one to detect physical losses at the time they occur.

Form 1 *a* and *b* of the accompanying diagram is a receiving report which is so arranged that the amount of material arriving in any kind of package can be recorded as compared with the actual amount received into the storage.

Form 2 *a* and *b* is a continuous inventory card, by means of which

Form 1a

MANUFACTURING, MATERIAL AND SPECIAL ACCTS.

RECEIVING RECORD

(OFFICE FILE COPY)

No. 20019

FROM Barrett Company — DATE REC. 10-20-20

Chicago — ORDER NO 37641

CAR NO Penn. R.R. 205164 — REC. NO 19462 J. A. L.

VIA — CHARGED — CHARGE NO 1

CONTENTS 54 Bags for Intrenue — G. N. WT. EXTENSIONS 44364 LBS.

TANK CAR CAPACITY — GALS.

OUTAGE — INS = — GALS. MINUS — GALS.

WATER — INS = — GALS. MINUS — GALS.

TEMPERATURE — °C = — PLUS GALS. MINUS — NET GALS. @ 15.6° C.

TANK MEASUREMENTS

					TOTAL ALL TANKS
TANK NO.		(Weight of bag drums, etc.)	check packed on steel pail	shipments in bags.	
INCHES START					
INCHES FINISH					
NET INCHES					
LBS. GALS. PER INCH					
TOTAL LBS. GALS.					

50 CONTAINERS 54 Bags

GROSS WT 44364 — TARE WT 909 — NET WT. 43455

DATE UNLOADED 10-22-20 — 107

James Dyson — FOREMAN

Form 1b Back of Receiving Record

INDIVIDUAL CONTAINER WEIGHTS

NUMBER OF CONTAINERS RECEIVED _____ STYLE OF CONTAINER _____

GROSS LBS.	TARE LBS.	NET LBS.	GROSS LBS.	TARE LBS.	NET LBS.	GROSS LBS.	TARE LBS.	NET LBS.
855	16	839	817	15	802	856	17	808
867	16	851	831	19	812	801	19	782
816	13	803	846	14	832	865	13	852
861	18	843	891	18	873	516	16	498
883	17	866	867	19	848	875	17	858
870	20	850	889	16	873	897	19	878
819	21	798	817	15	802	3370	100	3270
851	18	833	852	19	833			
856	18	838	871	18	853			
816	17	799	895	13	882			
870	18	852	817	19	798			
863	16	847	815	17	798			
897	19	816	853	16	816			
885	21	864	859	18	821			
817	18	799	817	18	799			
818	15	803	815	17	837			
869	17	816	862	15	847			
814	14	800	866	19	847			
865	19	846	862	16	836			
821	20	801	818	21	857			
885	21	834	861	19	867		Scale	
869	18	851	819	18	801	10309	804	10305
851	17	864	828	17	811	10785	805	10360
876	18	814	815	21	794	2570	100	2770
TOTALS 10709	804	10305	10785	805	10360	44364	909	43455

the individual foreman keeps a record of each lot of each material placed under his supervision. On it he records every movement in or out of the tank, bin, lot of drums or barrels, or whatever the

Form 2a **TANK INVENTORY** Inventory No. b-k

Material Drug Oils Tank No. 211 Cals. per Inch 402 Card No. 1

DATE	HOUR	READING INCHES	READING GALLS	DIFFERENCE RECEIVED	DIFFERENCE PUMPED OUT	FROM OR TO	REPORT CARD NO.
10 1 20		10	4 100				
10 4 20		50	19 000	8000		Brwd 400	16663
10 6 20		55	22 000	10000		S D & Tr 1490	19971
10 8 20		40	16 000		6 000	Shell 91	22810
10 16 20		63	25 200	9200		Brwd 1090	20109
10 14 20		39	15 600		9600	Shell 84	23811
10 24 20		10	4 100		11 600	" 85	22817

Form 2b **PACKAGE INVENTORY** Inventory No 10 200

CONTAINER 100 gal Drums MATERIAL 95% Acetic Cresylic Acid Card No —

DATE	HOUR	ON HAND No OF CONTAINERS	ON HAND LBS OR GALS	RECEIVED	USED	FROM OR TO	REPORT CARD NO
10 1 20		6	5849				
10 1 20		8	7690	1841		Shell 71	24167
10 2 20		1	893		6797	Barrelcoal	16904
10 3 20		12	12967	12074		Shell 72	24167
10 6 20		11	10263		2704	Hoppes	7219
10 8 20		15	14555	4292		Eagle Oil Chem	16181

storage may consist of, and in addition must show the source of incoming material, the point to which outgoing material has been sent, and give the identifying number of the card on which the amount moved has been recorded. Each foreman is provided with a calibration card for each one of the group of tanks for which he is responsible, from which he can read directly the gallons corresponding to each of his measurements.

Forms 3 and 4 *a* and *b* show two kinds of operation records upon which can be entered figures representing almost any kind of operation. For a discontinuous operation, the charge and corresponding production are recorded on the upper and lower halves of the same card. For a continuous operation two forms are used, one for recording the successive charges, and the other the successive productions. The latter has a space on which to record at monthly intervals the amount of material in the apparatus at the end of the month, so that the production corresponding to the charge for the period can be calculated.

Form 5 shows a form arranged for record of transfer of material

Form 3 OPERATION RECORD

Car No. 3013

Bengal DEPARTMENT

APPARATUS Still NO. 61

DATE CHARGED 6/20 1920 DATE FINISHED 1921

STARTED 6 A.M. FINISHED 12 M. TIME 30 HRS. — MIN.

CHARGE

MATERIAL	KIND OF PKG OR TARE NO.	NO. OF PACKAGES	START	FINISH	INS	GALS.	LBS.
Ner Bengal	344		100	50	50	10 000	
TOTAL							

PRODUCTION

Ner. Bengal	341		10	35	25	5600	
Ner. Toluol	322		4	11½	3½	700	
A. N. Bengal	343		69	86	17	1900	
Ner. D. T.	324		77	79	1	200	
Residue	341		77	79	2	1000	
TOTAL							

REMARKS

Jos Mueller FOREMAN

Form 4a

MONTHLY REPORT OF CONTINUOUS OPERATION

Naphthalene DEPARTMENT

APPARATUS Ner Benz & Nitrate NO.

CHARGE OF Ner Naphthalene

MONTH OF June 1920

DATE	KIND OF PKG OR TANK NO.	NUMBER OF PACKAGES	START	FINISH	INCHES	GALS	LBS.
6-1-20	Ner Process						210.981
6-2-20	79		100	46	14		22.400
6-3-20	80		396	360	16		14.400
6-10-20	79		184	167	15		37.000
6-14-20	79		167	153	14		22.400
6-15-20	79		153	137	16		25.600
6-16-20	80		390	370	20		40.000
6-21-20	80		370	354	16		25.600
6-24-20	81		360	340	20		40.000
6-26-20	81		340	319	21		41.000
6-30-20	79		137	116	17		27.200
TOTAL							340.981
IN PROCESS							90.961
TOTAL PRODUCTION							249.920

FOREMAN

Form 4b

MONTHLY REPORT OF CONTINUOUS OPERATION

Naphthalene DEPARTMENT

APPARATUS Ner Benz & Nitrate NO.

PRODUCTION OF Purified Naphthalene

MONTH OF June 1920

DATE	KIND OF PKG OR TANK NO.	NUMBER OF PACKAGES	START	FINISH	INCHES	GALS	LBS.
6 1	191		100	130	30		45.000
2	191		130	146	16		24.000
3	163		174	184	10		30.000
10	196		116	126	6		9.000
14	196		126	136	10		10.000
15	163		184	154	10		15.000
16	191		146	160	14		15.000
21	191		160	170	10		15.000
22	191		170	190	14		21.000
26	196		136	156	20		30.000
29	196		256	270	14		21.000
30	191		190	220	30		45.000
TOTAL PRODUCTION							299.000

Jos Mueller FOREMAN

Form 5

MEMORANDUM TO COST DEPT. No. 36240

STOCK TRANSFER

DATE 11/20/20

FROM Light Oil Dept. DEPT.

MATERIAL	TANK NO. OR KIND OF PKG	NO. OF PKGS	START	FINISH	INS	GALS	LBS.
Benzol Xylol Solvent	198		210	200	10	1000	

FOREMAN Jos Mueller

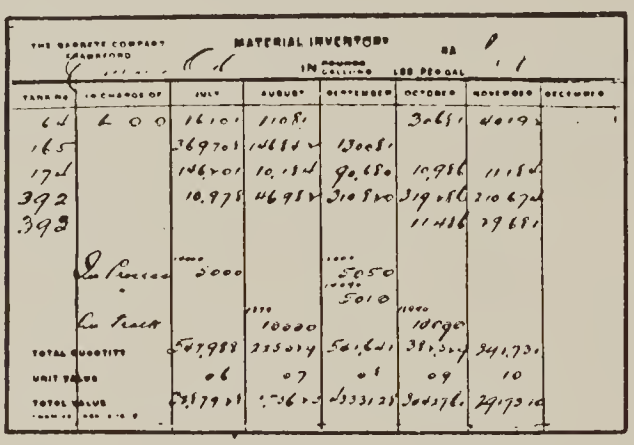
TO Tar Acid Extraction DEPT.

Benzol Xylol Solvent	210		188	197½	9½	960	

FOREMAN L. Roberts

from one part of the plant to another, where such material is not going through a process, and enabling a record of discrepancies between delivered and received amounts.

Form 6 contains a complete list of all apparatus under the charge of each process foreman, on which to record the material charged to the apparatus, the production from which is incomplete at the time of the inventory.



THE BARRETT COMPANY
FRANKFORD

MATERIAL INVENTORY

TANK NO.	IN CHARGE OF	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
64	L O O	16101	11081		3651	40192	
165		369701	14884	13008			
174		146701	10134	9065	10956	11154	
392		10975	46954	31054	31965	21067	
393					11416	19681	
	Le Roux	5000		5050			
	"			5010			
	Le Roux		10000		10090		
TOTAL QUANTITY		547988	235014	56,642	38,534	341,734	
UNIT VALUE		06	07	08	09	10	
TOTAL VALUE		32,879 01	16460	4533125	346876	2917310	

THE BARRETT COMPANY
FRANKFORD

INVENTORY OF MATERIALS IN PROCESS

Benzol DEPARTMENT
DATE Nov 1, '20

APPARATUS	MATERIAL	INCHES	GALS	100
Still 61	M.T			
St. 11 64	Drip Oil	Chg	9870	
5530				
	Cr Benzol	From	1178	
	" Toluol	"	1339	
St. 11 63	R/C P Thick	Chg	10387	
5033				
St. 11 64	Drip Oil Res.	Chg	9075	
	Cr Toluol	From	1058	
	Cr T.X.	"	1340	
St. 11 65	M.T.			
Agt 1	Cr Benzol	Chg	5000	
Agt 2	M.T.			

Jno Macleod FOREMAN

Form 7 is used to determine the inventory of each material in the plant at the end of the month, or at the end of whatever the cost accounting period may be. The figures on this inventory card are posted from the running inventory cards kept by the foreman.

From these reports, properly checked and recapitulated, a complete ledger statement can be made up, which, if the records have been accurately kept and carefully checked, should give an exact balance. Inasmuch as every amount of material moved has been recorded on one or the other of these forms, and the movement checked by the cost department, there is no possibility except through human fallibility (that troublesome factor in all "systems") of any quantity of material not being on the cost department records.

Let us turn now to the consideration of the statistics which should be obtained from a cost department to control properly the operations in a chemical factory.

The manner in which the figures are presented, if they are to be used, is important. First, no matter whether one is studying the whole plant or any particular part of the plant, one should go from the top down. The first figures examined should represent a summary of the expense of the operations under examination; they should omit detail and present a birdseye view. It is not difficult to remember, say, twelve items going to make up a total, nor to understand and remember the relation between twelve such figures. If it is attempted to study a total comprising 144 items, the average mind merely becomes confused, arrives at no decision, and no picture of the operations represented by the figures remains. Condense the 144 figures, however, into twelve sub-totals, the relations between these are easily grasped and they furnish a definite picture. Analyze each one of the twelve items further into twelve more, and each of the subdivisions becomes clearer and more intelligible as its detail is studied. The twelve principal subdivisions then become mental pegs on which to hang the remaining 132 of the figures in easily comprehended groups. Skillful summarization is the secret of useful statements. Diffuseness is the curse of cost accounting.

The total list of reports submitted, each covering monthly or longer intervals, might be somewhat as follows:

1. Complete balance sheet showing all the money spent during the month, and the main departments where the expense was incurred.

2. Analysis of profit.

3. Analysis of the total cost of all production under a few headings of direct expense.

4. The volume of production from, and cost of the working of individual processes or crudes. (The form of this report should be particularly noted. It does not provide for the computation of the costs of intermediate materials; these are supposed to be estimated by the technical staff. By estimating the value in finished products of the intermediates used and produced, the yield on the entire process can be calculated. The attempt to get a cost on each operation of a process is usually more expensive than the results are valuable.)

5. Analysis of the plant expense.

6. Analysis of cost of repairs.

7. A detailed statement of sales, giving volume and value for each commodity. This form is not illustrated.

PLANT BALANCE SHEET - JUNE 1, 1920

			May 1st	June 1st	Increase	Decrease
May 1	Asset value as per Financial Statement	2,000,000.00				
	June expenditures as per Voucher Record and Journal entries	500,000.00				
Assets						
	Cash		25,000.00	26,000.00	1,000.00	
	Accounts Receivable		15,000.00	18,000.00	3,000.00	
	Merchandise Inventories		500,000.00	460,000.00		40,000.00
	Stores and Supplies Inventory		100,000.00	110,000.00	10,000.00	
	Fuel		20,000.00	25,000.00	5,000.00	
	Real Estate		200,000.00	250,000.00	50,000.00	
	Buildings		400,000.00	500,000.00	100,000.00	
	Machinery and Tools		600,000.00	650,000.00	50,000.00	
	New Construction		100,000.00	25,000.00		75,000.00
	Furniture and Fixtures		25,000.00	31,000.00	6,000.00	
	Prepaid Charges		15,000.00	12,000.00		3,000.00
			2,000,000.00	2,107,000.00	225,000.00	118,000.00
					118,000.00	
					107,000.00	
	Production Cost for May				393,000.00	
	Total Expenditures				500,000.00	

REPORT 1.

ANALYSIS OF PROFIT

MONTH June, 1920

Process or Crude	Factory Cost	Sales & Administration Cost	Total Cost	Total Return	Profit	Loss	Six Months Jan to June	
1	25,000.00	2,500.00	27,500.00	32,500.00	5,000.00		35,000.00	
2	10,000.00	1,000.00	11,000.00	13,000.00	3,000.00		15,000.00	
3	75,000.00	7,500.00	82,500.00	80,000.00		2,500.00	2,500.00	
4	122,000.00	12,200.00	134,200.00	150,000.00	16,000.00		100,000.00	
5	2,000.00	200.00	2,200.00	2,500.00	300.00			10,000.00
6	180,000.00	18,000.00	198,000.00	190,000.00		9,000.00		42,000.00
7	200,000.00	20,000.00	220,000.00	250,000.00	30,000.00		150,000.00	
Totals	614,000.00	61,400.00	675,400.00	718,000.00	57,000.00	11,500.00	302,500.00	52,000.00
Net Profit					45,500.00		250,000.00	

REPORT 2.

PRODUCTION COST

MONTH June 1920

	Labor	Material	Sub Total	Total
Opening Inventory Naked Materials				748,108.74
Purchases				314,932.64
Cost of Plant Operation				
Process Labor	38,602.49		38,602.49	
Salaries	1,500.00		1,500.00	
Fuel & Power	4,146.74	29,000,00	33,146.74	
Teaming, Carting & Loading			664.82	
Repairs	16,000.00	14,000.00	30,000.00	
Expense	20,000.00	7,500.00	27,500.00	
Rents			200.00	
Taxes			966.30	
Insurance			4,534.15	
Depreciation			9,531.92	146,646.42
	80,249.23	50,500.00		1,209,687.80
Closing Inventory Naked Materials				860,379.88
COST MATERIALS TO BE PACKED				349,307.92
Opening Inv.Packed Mtls.& Empty Pkgs.				156,849.91
Material Purchased			2,260.66	
Packages Purchased			20,400.00	
Cost of Packing & Shipping				
Labor	3,791.02		3,791.02	
Teaming, Carting & Loading	1,000.00	994.49	1,994.49	
Expense	273.38	2,000.00	2,273.38	30,719.55
	85,313.63	53,494.49		536,877.38
Closing Inv.Packed Mtls.& Empty Pkgs.				143,877.38
COST MATERIAL SHIPPED				393,000.00

REPORT 3.

COST SHEET

Month

Process or Crude

CHARGE																
Expenses		Raw Materials					Intermediate Materials					Finished Products					Total Costs
		Name	gals	lbs	unit value	Value	Name	gals	lbs	unit value	Value	Name	gals	lbs	unit value	Value	
Labor Salaries Fuel & Power T.C.&L. Repairs Expense Rents Taxes Insurance Depreciation							Intermediate materials usually form an element of uncertainty particularly when the cost period is short. Their use and production tends to obscure yield, their rates or cost is usually a matter of judgement										
Totals																	
PRODUCTION																	Sales Values
												The division of the cost among the finished products is usually a matter of judgement					
Totals																	

REPORT 4.

EXPENSE

MONTH: June 1920

ANALYSIS			SUMMARY	
Purchasing Dep't		1,200.00		
Traffic Dep't		1,300.00		
Accounting Dep't		3,250.00		
Production Cost	1,000.00			
Construction Cost	650.00			
Finance & Accounting	600.00			
Paymaster & Timekeeping	1,000.00			
General Office		2,000.00		
Repair & Construction	500.00			
Stenographic	1,000.00			
Mail & Messengers	500.00			
Management		500.00		
Stationery, Postage, Telegrams		800.00		
Traveling Expenses		150.00		
Janitors & Washers		500.00		
Telephone		300.00		
			OFFICE	10,000.00
			LUNCH CLUB	250.00
Salaries—Routine, Samples, Office		5,500.00		
" Research, not charged direct		3,300.00		
Stores & Stationery		500.00		
Janitors & Washers		500.00		
Miscellaneous		200.00		
			LABORATORY	10,000.00
Plant Nurse & Hospital Bills		350.00		
Plant Doctor		250.00		
Dispensary Supplies		200.00		
Payments to Injured		311.67		
		1,111.67		
Received from Insurance Co		111.67		
			MEDICAL	1,000.00
Guards		2,000.00		
Safety, Employment, Advertising		1,000.00		
Taxes, Water, Gas		1,000.00		
Janitors, Towels, Stationery		1,500.00		
Pension		150.00		
Team Hire		100.00		
			WORKS	5,750.00
			MISC.	200.00
TOTAL				27,200.00

REPORT 5.

REPAIRS

1920

	January	February	March	April	May	June
Department #1	8,473.23	8,732.74	11,655.90	6,570.78	9,866.89	
Department #2	2,340.85	1,390.46	2,116.37	5,116.62	5,308.05	
Department #3	2,349.95	3,219.46	3,527.78	4,555.02	2,131.17	
Department #4	1,115.20	1,769.93	2,709.23	1,397.20	1,243.10	
Department #5	454.76	98.33	482.05	229.86	152.02	
Department #6	3,023.10	2,345.91	2,759.09	3,889.46	3,391.90	
Department #7	7,919.71	9,881.38	8,410.23	8,954.38	10,641.59	
Department #8	919.20	3,640.71	3,505.93	5,253.94	6,557.24	
Department #9	6,123.99	6,702.45	14,203.04	11,824.40	18,013.47	
Department #10	32.44	114.82	1,108.38	1,138.17	228.18	
Department #11	965.13	3,423.14	1,410.00	2,941.49	3,505.01	
Department #12	447.69	3,073.85	315.91	794.90	344.29	
TOTAL	34,165.25	44,393.18	52,203.99	52,666.22	61,382.91	

REPORT 6.

COST ANALYSIS

These, together with a more or less detailed analysis of each, should constitute the bulk of the cost department's work. Much attention should be paid to the arrangement of data on the books so as to facilitate the preparation of such analyses as may be necessary from time to time to explain unusual fluctuations. It is much better to submit comparatively few summaries and to be prepared to furnish analyses of any of them quickly than to attempt the regular periodic compilation of many detailed statements.

The statement "Analysis of Repairs" (Report 8) is an example of a report gotten out upon request to explain an unusually large repair charge. That headed "Weekly Report of Construction" is a report for the use of the engineer on a construction job, which enables him to compare the amount of money spent to date on his work and the money appropriated to complete it. The "Laboratory Cost Sheet" is a monthly report to the chief chemist who may well be required to work under a budget; it includes all the expenditures for which he is responsible.

In presenting cost figures to the sales department month by month, one very general condition experienced is fluctuations in cost, due to the fact that repairs and other expenses are not incurred equally month by month. It is sometimes attempted to

ANALYSIS OF REPAIRS

DEPARTMENT Light Oil - Oils CHARGE NO. 6-A-1

Job	Description	Week June 1, 1920 Labor	Material	Week June 8, 1920 Labor	Material	Week June 17, 1920 Labor	Material	Week June 24,1920 Labor	Material
1	New bottom in Still #443	100.00	50.00	75.00	30.00	150.00	25.00	50.00	-
7	Repair flow box Still #441	5.00	3.00	-	-	-	-	-	-
9	Repair Line to Pump #165	1.50	-	10.00	4.50	-	-	-	-
21	New cock on Catchall Tank #3	2.50	10.00	-	-	-	-	-	-
23	Repair brickwork on Still #450	-	-	35.00	100.00	75.00	15.00	-	-
24	Repair steam leaks at tanks	-	-	4.00	1.00	10.00	1.50	15.00	3.50
	Material charged directly to dep't. (Oils, Waste, Ice, Clogs, etc.)		18.00		27.00		10.00		25.00
	Total Labor & Material per week	109.00	81.00	124.00	162.50	235.00	51.50	65.00	28.50

Total Labor & Material as above.....865.00

Direct Purchases (From Distribution Ledger).....150.00

Overhead (From Distribution Ledger).....155.00

1,170.00

Note

Repair costs should be so kept that such detailed analysis as this can be furnished readily on request, to explain, for example, unusual fluctuation in department total.

REPORT 8.

WEEKLY REPORT OF CONSTRUCTION

Appropriation No. 3169 Amount $22,000.00

Work Improvements and Additions Plant

Code No. 36-1657

	Cash Expenditures	Liability	Total for Week	Total to Date	Balance Unexpended
1920					
May 24	1,842.87	165.00	2,007.87	2,007.87	19,992.13
" 31	1,084.11	12,210.37	13,129.48	15,137.35	6,862.65
June 7	337.61	779.64	1,117.25	16,254.60	5,745.40
" 14	69.96	347.83	417.79	16,672.39	5,327.61
" 21	158.53	914.78	1,073.31	17,745.70	4,254.30

REPORT 9.

LABORATORY COST SHEET

MONTH June 1920

ANALYSIS		SUMMARY	
Salaries	4,200.00		
Supplies from Laboratory Stores	800.00		
Supplies from Stationery Stores	50.00		
Supplies from Repair Stores	25.00		
R. & C. Labor and Supervision	50.00		
Crude Materials from Stock	5.00		
Finished Materials from Stock	50.00		
Containers from stock	15.00		
Advertising	10.00		
		ROUTINE	5,205.00
Salaries	4,800.00		
Supplies from Laboratory Stores	225.00		
Supplies from Stationery Stores	5.00		
Crude Materials from Stock	2.00		
Finished Materials from Stock	2.00		
		RESEARCH	5,034.00
Salaries	150.00		
Supplies from Laboratory Stores	10.00		
Supplies from Stationery Stores	1.00		
Finished Materials from Stock	150.00		
Containers from Stock	25.00		
		SAMPLES	336.00
Janitors' & Bottle Washers' Wages	500.00		
Salaries	800.00		
Supplies from Stationery Stores	60.00		
Traveling Expenses	35.00		
Laundry	30.00		
Gas	25.00		
Electric Power	100.00		
Manufacturing Insurance	85.00		
Manufacturing Taxes	75.00		
Manufacturing Depreciation	300.00		
Water Consumed	65.00		
Repairs to Building & Equipment	350.00		
		SERVICE, etc.	2,425.00
TOTAL COST			13,000.00

Report 10.

equalize such expenses by setting up on the books deferred charges, so that a very heavy expense is not charged to the operations going on in the month wherein the expense was incurred, but is spread over a period of several months, or even a year. Such a method as this leaves so much to the judgment as almost always to lead to confusion, and possibly also to embarrassment; no one likes to have deferred charges on his books. In my opinion, the better way is to charge all such expense to the operations when incurred, and to flatten out the cost figures by averaging them over periods of say six to twelve months. This would mean that in January the cost submitted would be the average of the past six months of the old year and the first one of the new, and so on until the end of the first six months of the year is reached, when the cost may become cumulative from the first to the end of the year.

The money spent on costs covering the ground indicated here need not exceed 0.5 per cent of the payroll; the difference between good management and the best possible is, I should guess, about 10 per cent. The one almost universal trouble experienced with cost departments and systems is their tendency to spend more money on statistics than the use of the figures they submit can possibly save. Coupled with this is the tendency to attempt to turn out mechanically, month by month, large volumes of significant figures. The number of figures which a cost department is asked to produce each month should be cut down to the very minimum, and these should be only such as can be turned out by a mechanical routine and wherein as few elements of judgment enter as possible. Analysis beyond this point should be done by the technical staff of the plant, or by a department of cost analysis run, not by bookkeepers, but by men whose judgment is based on a real, solid understanding of the processes. The fewer and more simple the figures which the ordinary cost department run by bookkeepers and clerks with no operating experience and the greater the insistence that the technical staff of the plant take the figures, analyze and interpret them the more likely it is that valuable results will be obtained. An adding machine cannot think. It will say, for example, that a certain product is unprofitable; its manufacture, therefore, is discontinued. To your surprise, however, instead of saving the loss, a still greater loss is incurred. Shutting down the plant has not decreased outgo as much as it has decreased income. Depreciation, insurance, taxes, still continue; the plant begins to deteriorate and assets to drop; the overhead allotted to the plant cannot all be cut out and has to be carried by other processes. In general, the only safe way to determine whether a production shall be discontinued, increased or diminished is to disregard the individual cost figure, and to sit down and figure the effect the proposed change will have on the total income of the plant on the one hand and the total outgo on the other. Not until that is done can one be in a position to say whether the proposed change will result in greater profit, or in the least possible loss.

Chemists and Engineers Ought to be Familiar with Accounting Methods

In the Philadelphia *Public Ledger* of Feb. 18, 1918, a statement was made in one of the editorials that 95 per cent of the business men

of Germany are expert accountants. The continual association of values with materials and effort is an essential in the education of a successful chemical engineer. Of necessity it is omitted from his college training. The opportunity for doing it should be freely given in the industries.

The chemists and engineers in charge of our factories must be familiar with accounting methods. The economics of the factory must come within the scope of their activities. They must be able to use the help of the accountant. The officials of a corporation must be able to rely upon their technical men for sound advice, not only in the realms of physics and chemistry, but in economics also. Webster says that "economics is the art of regulating receipts and expenditures so as to insure a proper profit." Surely this is an art we need to acquire and not leave to a bookkeeping department.

What Otto Witt said in 1887 is truer than ever today: "The success of a process is no longer, as formerly, dependent upon the careful preservation of manufacturing secrets, but above all upon businesslike control, both within and without."

Discussion

The President: Mr. Peterkin has given us a very timely paper on a very important subject. I have enjoyed it very much, and I believe we all have. It is now open for discussion.

Dr. Langmuir: The chief trouble—it may not have much bearing on this, but the trouble with most costs is that the selling department come back at you and say: "Well, that is the price the other fellow makes and we have got to meet it, and we don't care what your costs are; we have got to sell the goods."

The President: Doctor Toch, would you like to make some remarks on the subject.

Dr. Toch: I have got to save my voice for later on.

Dr. Reese: That paper will be published, I suppose.

Secretary Olsen: Yes, sir.

Dr. Reese: I think it is an extremely interesting paper, and I would like to be able to study it more carefully.

The President: So would I, and I would like also to have our bookkeeping department study it.

WELFARE PLANS OF THE DUPONT COMPANY

By CHARLES L. REESE

Read at the New Orleans Meeting, December 6, 1920

Some time ago, in talking with Dr. Wesson on the welfare plans of the duPont Company, he asked me if I would say something before this meeting on that subject, and I will do what I can during the fifteen minutes alloted to me.

It is quite a task, as we have several of these plans, and it will be impossible in the limited time I have to do more than touch the important points. I will mention what these different plans are, to whom they apply, the benefits derived from them, etc., and if we have any time left, I shall be very glad to answer any questions on them.

The Bonus Plan

The first, and the one I consider the most important, is our Bonus Plan, whereby employes who have contributed in an unusual degree to the success of the company by their inventions, ability, industry and loyalty, and whom it is deemed desirable to have interested in the business as stockholders, are awarded stock bonuses. The amounts of these may run from one share to many times an employe's yearly salary in either common or debenture stock. These are divided into two classes, "A" and "B."

The "A" Bonuses are for inventions, or other conspicuous service of any employe, regardless of his length of service, and each case is considered strictly on its merits. For instance, if any employe discovered a new process for the manufacture of say, nitroglycerine, whereby the yield was increased one per cent, he may, or most likely, he would receive an "A" Bonus for his discovery, receiving a percentage of the actual saving to the company for a number of years by the adoption of his discovery, or invention. An increase of only one per cent in a yield, or a saving of only one per cent in the amount of a raw material used, or the substitution of one material for another, when applied to the enormous quantities involved, especially during the war, has resulted in employes receiving small fortunes as "A" Bonuses.

An ordinary inventor may get the benefit of his invention for seventeen years through a patent, but it generally takes a patentee, who has not the backing of a large corporation, several years to get his patent in a paying condition, and it generally takes a very large expenditure of money. The company does all that—it spends all the money, applying the invention immediately, and the inventor may receive anywhere from five to ten up to twenty per cent of the saving for five years, depending on the merits of the case.

Of course the difficulty with any plan of this kind is that some may not be satisfied, as there are a great many factors to be considered in determining the percentage a man should receive, such as the degree of originality, whether it is within the man's regular line of work, or something entirely outside of his line, etc., and where men are working together, it is sometimes a very difficult problem to be absolutely sure you have the right man, and he receives the right amount. Nobody can do any more to make a thing fair than to do the best they can, and my feeling is that it is better to give people the benefit of the doubt, as we always do, and to give those men who actually have a clear case, the benefit of such a system, and let the others suffer, rather than not let anybody have the benefit of such a system, because there is no law requiring such a scheme for employes, when their time is paid for, and all the facilities given them for carrying on their work.

If a man receives an "A" Bonus, this does not in any way interfere with him receiving also a "B" Bonus. These "B" Bonuses are in the nature of profit sharing with those who have contributed most in a general way to the company's success. The total to be distributed amounts to seven per cent of the surplus left from the yearly earnings after the deduction of debenture stock dividends, and five per cent dividends on the common stock. You can see that in times such as the war times, when profits were very large, this ran into a very large sum of money. No award is made to an employe under Class "B" unless he has been in the continuous service of the company at least two years, but exceptions may be made to this rule in special cases as to the time of service, if approved by an affirmative vote of three fourths of the Executive Committee. During the war, in the time of large profits, there were a great many of these special cases, where men did very good work, but had not been in the employ of the company more than a year, and they received "B" Bonuses. These "B" Bonuses in some cases

amounted to as much as $30,000 to $50,000 during the period of great profits to the company, and resulted in making employes all the way down the line very comfortable, and some of them rich.

One of the benefits of the bonus plan is to encourage good men to remain in the employ of the company, and therefore, while a man receives all the dividends when due on stock awarded him, after the award is made, he does not actually receive the stock itself until the expiration of a five-year period after the year for which it was awarded. When the stock is awarded, the recipient is charged with it at the par value, and each month he is credited with one sixtieth of this amount; thus at the end of sixty months, or five years, the stock has paid for itself, and is delivered to the holder. This is simply a book transaction, but if at any time an employe having stock voluntarily resigns from the company, to accept a position with another concern, his stock is cancelled, and he receives outright the amount credited to his account, as of the date of his resignation. If it is necessary for an employe to resign on account of ill-health, or to return to college to finish his education, or for some other good reason, or he is discharged from the company on account of lack of work or for any other reason beyond his control, his case is brought to the attention of the Executive Committee, and in practically all of these cases, he is allowed to retain his interest in the bonus stock awarded him, just as though he were still in the employ of the company. If an employe should die while in the company's employ, his estate is immediately paid the entire amount of bonus awarded him, without having to await the expiration of the five-year period.

The Suggestion Plan

This plan is for the purpose of encouraging suggestions by employes for the improvement of company processes, methods and equipment. It is, in a measure, similar to the "A" Bonus plan, but on a smaller scale. If any employe reports a suggestion for an improvement that is accepted, he is rewarded in cash according to the value of the suggestion adopted, but he can not receive over two hundred dollars for it. If it is decided he should receive more than this amount, it comes under the "A" Bonus plan.

Merit Pay Plan

The Merit Pay plan is for rewarding continuous and satisfactory service for works' payroll employes. It is with our company, the same as with other concerns, very desirable to have our good payroll men remain with us just as long as possible, as the longer they stay with us the more valuable they become, particularly those handling our complicated and dangerous operations, and as an incentive for them to remain, all payroll men who have been in our employ continuously for two years receive with their regular pay extra pay amounting to five per cent of their regular pay, those who have been in our employ continuously for five years receive ten per cent of their regular pay, those who have had ten years' continuous service receive fifteen per cent, and those who have over fifteen years' continuous service receive an extra 20 per cent. We have very few men voluntarily resigning from our employ who receive this extra pay.

This plan may also be used in a disciplinary way. The company reserves the right to discontinue this extra pay temporarily or permanently for infraction of our rules. The men thoroughly understand this, and generally they think twice before they break one, knowing they may lose their extra pay for two or three months.

Insurance Plan

In our insurance plan, all employees who have been in our service from six months to one year receive a one-thousand-dollar life insurance policy, without any cost whatever to them. Those who have from one to two years' service receive a policy for $1,100; those having from two to four years' service a $1,200 policy; three to four years a $1,300; four to five years a $1,400, and those who have over five years a $1,500 policy.

If an employee dies while in the employ of the company, his estate receives this insurance in twelve monthly payments. If he has not reached the age of sixty, and is permanently disabled, he may himself receive his insurance in the same manner. If he leaves the service of the company for any reason whatever, his insurance is stopped, as far as the company is concerned, but he can himself continue it, if he so desires, by paying the necessary premiums to the Insurance Company.

Benefit and Pension Plan

Through this plan provision is made for compensation to employees of the company who are injured in the performance of their duties, for compensation to dependents of those killed in the performance of their duties, and for retiring upon pension those employees who have rendered satisfactory service over a number of years, and whom it is advisable to relieve from further active duty on account of advanced age, sickness, or other incapacity. Any employee who has been in the continuous service of the company for fifteen years or more is eligible for a pension, provided he is either physically or mentally incapable of performing his duties in a satisfactory manner, and he may receive one and one half per cent of his average monthly pay during the last five years of his service, multiplied by the total number of years in which he was continuously employed. Merit pay given for length of service, and extra compensation which salary employees have been receiving for the last few years shall be included in computing pensions. In the event of the death of a pensioner, the Pension Board may, in its discretion, authorize the pension to be paid in whole or in part to his widow, minor children or other dependents, in cases where such a pension is necessary for their support.

Stock Subscription Plan

By this plan, any employee who has been in our service for one year or longer may subscribe to debenture stock. Before this year employees were permitted to purchase debenture stock at whatever it cost the company to buy it on the market, paying for it in installments, if they so desired, at only two dollars per share per month. After this stock was paid for, an extra dividend of three dollars per share was paid yearly for five years, if the stock was held that long. The idea of this plan was to encourage employees to become stockholders, as well as to save money.

One of the objections to this scheme, is that owing to the fall in values, the man who paid ninety-three dollars per share for his debenture stock during the early part of last year, can not sell it for more than seventy-seven dollars per share now. When there is a profit nobody complains, but if there is a drop in value, and they want to turn their stock into money, everybody does, so we have devised a new scheme, so that no one can lose any money on his stock, and I think this is one of the best schemes I have ever seen.

The new plan adopted this year allows employees to subscribe to debenture stock to the extent of one third of their annual pay, which pays six per cent cumulative dividends. He pays par value, one hundred dollars per share, for this stock regardless of what the market value is, and when he desires to sell it, he sells it back to the company for one hundred dollars per share. He may pay for this in installments, if he so desires, but he can not get the full value of the plan until the stock is completely paid for.

After it is paid for, if an employee's service is one year, and less than two years, he gets one dollar per share extra for that year. This gives him seven per cent. If he has been with the company two years and less than four, he gets two per cent extra. That gives him eight per cent. If he has been with the company four years and less than seven, he gets three per cent extra, which gives him nine per cent. And if he has been with the company seven years or over, he gets four per cent per annum, which gives him ten per cent.

In addition to this, if the company's earnings for the previous year on its total investment are more than eight per cent, but less than nine per cent, each participant receives an additional one dollar per share per annum. If the earnings are more than nine per cent but less than ten per cent, he receives two dollars per share per annum. If the earnings are more than ten per cent but less than eleven per cent, he receives three dollars per share per annum. If they were more than eleven per cent, but less than twelve, he receives four dollars per share per annum, and if they were more than twelve per cent, he receives five dollars per share per annum.

As an illustration of this, take a man who has had seven years, service, and the earnings were twelve per cent. For each share of stock this man held under this plan he would receive the regular dividend of six dollars, four dollars for his service and five dollars on account of the earnings, or fifteen dollars a year on each hundred dollars invested, so it would not take him very long to pay for it at that rate. If an employee dies, his estate gets one hundred dollars back for every hundred dollars put in, or if at any time he wants to sell his stock, he gets back one hundred dollars for every hundred dollars put in. If the market value goes above par, he is not required to sell it back to the company.

I can not conceive any better inducement to employees to save

money that that offered by this stock subscription plan. The only ones in the company who can not save under this plan are the directors. The directors of the company are not allowed to enter into this.

Discussion

THE PRESIDENT: Gentlemen, we are all very much indebted to Dr. Reese for a very able exposition of a very interesting subject. The paper is now open for discussion.

SECRETARY OLSEN: I would like to ask Dr. Reese what proportion of the employees get the benefits of each of these two plans, especially the plans for inventions and those things?

DR. REESE: It depends upon the earnings a good deal. During the war, when our earnings were large, nearly everyone who was any good got bonuses, but now when the earnings are not so large, there is not the amount of money available, and we naturally can not be quite so liberal.

The head of each department has the privilege of distributing the "B" Bonuses. We have to figure out what we consider the best men, and distribute it among them as equitably as possible. Of course, the head of each department takes the recommendations of his sub-heads. For instance, in my department, I take the recommendations of the laboratory heads. There are five laboratories, and each one of those laboratory heads makes recommendations for the men that come under them. I handle the heads of the laboratories, and the men in the Wilmington office. The fact of the matter is, the assistant director recommends to me the men in the Wilmington office, and after getting all of these recommendations, I go over them with the men who make the recommendations, and try to distribute them as equitably as possible.

DR. REESE: Did you not tell me your company had an insurance plan, Dr. Wesson?

DR. WESSON: Yes. We have the insurance plan, but if a man leaves the company, his insurance stops.

DR. SMITH: Do the workmen get theirs monthly or yearly?

DR. REESE: The workmen get every month their five, ten, fifteen or twenty per cent. That is what we call the extra compensation. But they are also eligible for the "B" Bonuses and also the "A" Bonuses. Of course, this does not cover those things which a great many companies are doing now, building houses for people, and club houses, and entertaining them, etc.

DR. MOORE: Mr. Chairman, I would like to ask Dr. Reese—we have been keeping in our company for about three years a record of the overturn in the mill. We find that the overturn is in the wrong place; that most of it is in the unskilled labor, and that there is not enough overturn in the heads of departments, so that dry-rot is liable to creep in. I would like to ask Dr. Reese if the bonus plan tends to shift the overturn more into the skilled labor, or rather to prevent the overturn in the unskilled labor.

DR. REESE: We generally call that "turnover." I do not know that it makes any difference. The turnover with the unskilled labor is usually very large, because these men do not stay long enough as a rule to get the benefit of these things. When they do, they become what we call "semi-skilled" labor, because if they stay long enough, they are liable to get some job that means doing some one thing. Of course, during the war, the turnover was perfectly enormous. It was with everybody.

DR. LANGMUIR: I would like to ask Dr. Reese how he keeps his research chemists satisfied. The German plan, as I understand it, is to keep the research chemists separated by themselves, and each one reports his results only to the directors. In your case, do you encourage the research men to talk among themselves?

DR. REESE: Dr. Langmuir, I would not be the head of that chemical department if we did not. I think a man who tries to work out a problem by himself will die of dry-rot very quickly, according to what our friend Dr. Moore says.

I recognize the desirability of the German system, but my principle of operating the research end of the duPont Company has run over a period of about twenty years, and my policy has been exactly the opposite from the German. I have seen the German methods in operation. I have visited some of the largest research laboratories in Germany, and also the plants that those laboratories were supposed to be working for, and there was an absolute lack of cooperation.

My opinion, if you want it, gentlemen, is that no man can handle and direct production and research at the same time efficiently. He is either going to be a man who is very much interested in the research, and will neglect his production, or he will be very much interested in production, and neglect his research. I do not believe in that system.

As far as putting men in rooms by themselves, it is a very great

help in deciding who did the work, but the men will not develop. One of the most important things, in my mind, in conducting research work is to develop men, and you can not develop men by shutting them up by themselves.

Undoubtedly we lose a great deal by the freedom with which we allow our men to discuss things among themselves, as when they leave us, they carry their information to somebody else, but I do not think they go to Germany, and if they don't take it to Germany, I don't care. We get a great deal more out of them—an enormous amount of cooperation when we are carrying work through from the laboratory into what we call the semi-works scale, and I think Mr. Howard will bear me out that we have the finest semi-works equipment of anybody in the world. We bring the men into that semi-works plant, and teach them the operation before starting a plant. Where we have started a process by running it through the semi-works step first, before building a big plant, we have never had any difficulty in operating processes. Where we have had to build plants and start the operation of them before going through the semi-works, we frequently have had a great deal of difficulty, and it has cost us a lot of money.

THE SALVAGING OF SAG PASTE

By C. B. MOREY

Read at the New Orleans Meeting, December 7, 1920

Sag paste was a material developed during the war as a defense against surface burns from mustard gas. Its name s-a-g is simply gas spelt backwards. It was manufactured by several different companies working under formulas furnished by the Government. The only reference to it which we have found in the literature, is the mention made in the *Journal of Industrial and Engineering Chemistry*, for May, 1919, of an address entitled "Protective Ointments," by R. E. Wilson, given at the spring meeting of the American Chemical Society, held in Buffalo, but we have found no copy of this address, nor even an abstract of it.

After the signing of the Armistice there was a large amount of sag paste in this country and France. The material was finally collected at Edgewood Arsenal, and offered for sale under competitive bidding. In the issue of *Chemical and Metallurgical Engineering*, advertising page no. 139, dated March 10, 1920, the accompanying advertisement appeared:

The data there given were very meager to form the basis of an intelligent plan of salvaging the sag paste. Fortunately, Larkin Co., an employee of whom I have the good fortune to be, made a large amount of this paste during the war, and we were therefore familiar with it and its peculiarities. We at once ordered two sample cases, and turned them over to our Research Laboratory. Mr. L. F. Hoyt, the director of the laboratory, ably assisted by Mr. H. V. Pemberton, worked out a tentative plan for salvaging the sag paste. It so happened that the sample cases consisted entirely of formula XII–A, Type 1, and later development proved that this type was only a small part of the whole.

Larkin Co. was the successful bidder and the entire amount of sag paste was sold to it.

We instructed our representative whom we sent to Edgewood Arsenal to ship us in the first car, every variety of the paste that he could find. That car actually brought nine different varieties,

and more were found later. Fortunately, we found that they could all be divided into two classes. Those which were first made, consisting of zinc stearate and an oil or fat. For brevity, we called all these the paste variety. Some of these were so hard that when the cap of the containing tube was removed, the tube could be

March 10, 1920
Chem. & Met. Eng.

SEARCHLIGHT SECTION

War Department

CHEMICAL WARFARE SERVICE

Offers for Sale by Informal Bid

SAG PASTE

Approximately 8,000,000 Tubes
(Total Net Weight—Estimated 3,000,000 Lbs.)

SAG PASTE is an ointment prepared in the United States by several large manufacturers under the following formulas, for protection against burns.

FORMULA NO. 66

COMPOSITION:

40 parts by weight of Zinc Oxide, 100 mesh U. S. P.
20 parts by weight of Benzoinated Lard.
20 parts by weight of Refined Raw Linseed Oil.
20 parts by weight of Adeps Lanae, U. S. P.
1 part by weight of coloring matter.

FORMULA NO. 146

COMPOSITION.

45 parts by weight of Zinc Oxide, 100 mesh U. S. P.
10 parts by weight of Benzoinated Lard.
30 parts by weight of Refined Raw Linseed Oil.
15 parts by weight of Hydrous Lanoline (adeps lanae, U. S. P.).
Coloring matter.

Note: Coloring matter shall be non-poisonous and of such a color as to give the sag paste a good flesh tint.

FORMULA XII-A—COMPOSITION—TYPE I.

Soya Bean Oil — 62%
Zinc Stearate — 38%

SOYA BEAN OIL. The soya bean oil used shall be a high grade commercial oil free from fatty acids.
ZINC STEARATE. The zinc stearate shall be standard U. S. P. zinc stearate.

The United States Government does not guarantee the commodity offered for sale to conform to any of the above formulas.

This paste is put up in collapsible metal tubes of two sizes, similar to those used for tooth paste and other ointments. A large majority of the tubes weigh gross about 7½ oz. and tube empty 1¾ oz. The smaller size weigh gross about 2 oz. and empty about ½ oz. Some of the tubes are packed in wooden boxes. These boxes vary in capacity from 100 tubes each to 720 tubes each.

All of the SAG PASTE is located at Edgewood Arsenal, Edgewood, Maryland, and arrangements may be made for inspection at any time prior to March 21, 1920.

Here are the Conditions of Sale

This SAG PASTE is to he sold with the distinct understanding that the purchaser buys it "as is, where is," and without guarantee from the United States Government. BIDS CLOSE AT 11 A. M. EASTERN TIME, MARCH 31, 1290 No special form of bid is required. Bids may be made on your own letter head. No deposit is required with bid. Bids to be based upon price per pound, with the distinct understanding that the weight of the metal tube is to be included in determining weight. Make your offer for any quantity above 500 pounds. FORWARD BIDS TO CAPT E. C THOMPSON, MATERIALS' DISPOSAL SECTION, EDGEWOOD ARSENAL, EDGEWOOD, MARYLAND. Upon notification of award successful bidders must forward a certified check for 10% of the total purchase price within 48 hours. All materials must be removed and paid for within 60 days from date of notification of award The purchaser will not be required to pay storage charges during these 60 days. The Government reserves the right to reject any or al blids or any part thereof For further information about SAG PASTE or conditions of sale apply to MAJOR A. M. HERITAGE, CHIEF PROCUREMENT, SALVAGE & SALES SECTION, CHEMICAL WARFARE SERVICE, 7th & B STS, N. W., WASHINGTON, D. C.

stepped on without a single particle of the paste squirting out. How our soldiers ever got the stuff out of the tube and hastily anointed their face and hands with it, is a mystery. Some of it, on the other hand, was soft and fluid, being of the consistency of a slightly thickened oil. The formulas were changed later. These later varieties consisted of a mixture of zinc oxide, lard, hydrous lanoline and linseed oil. These we called the paint variety, for they were, in consistency and semi-drying properties, essentially a paint.

We found that the paste and paint varieties required different methods of treatment, and all the tubes had to be separated into these two classes. This could be readily done because the paint variety was considerably heavier than the paste variety. An operator with little experience could tell which was which, simply by picking up a tube. By far the greater majority of the paste was packed in the large block tin tubes. These tubes were supposed to be packed singly in cartons. The cartons were packed in strapped export cases holding 600 to 720 tubes. Later developments evidently forced the idea through somebody's head that these cases weighing between four and five hundred pounds each, could not be conveniently carried to the battle front, so the paste made during the latter part of the war was packed in convenient cases, holding one hundred tubes each. These cases made a neat, strong, compact unit that could easily be transported and distributed. Some of the paste was also put up in small 2-oz. tubes packed in thin cases about the size of egg crates. These we believe were of very early or foreign manufacture, as we found only the paste variety in them.

A large portion of the tubes were loose without any cases at all. Others were packed loose in bags, boxes, cases, or any convenient receptacle. The loose tubes had been exposed to the sun and rain. Part of the oil had leaked out, partially oxidized, and turned decidedly rancid. The tubes, cartons, rags and dirt were cemented together into one unholy, rancid, smelly mess. The government was wise when it sold the paste "as is" and "where is."

The values which the Larkin Co. had to salvage consisted of the wooden cases, the paper linings, the cartons, the block tin of the tubes, the zinc, and the fat. The fat consisted of stearic acid, lard, soya bean oil, linseed oil, and lanoline. Fortunately for our salvaging the lanoline was the most expensive ingredient and con-

sequently was not present in any larger quantities than necessary. We found also that some of the linseed oil possessed a strong fishy odor, which we could only account for by the fact that some of the paste had traveled to France and back and must have picked up its effluvium during its ocean voyage. The supposition that any manufacturer could have unwittingly mistaken fish oil for linseed, hardly seems reasonable. The practical effect of it was probably to make death more pleasant to the soldiers who had to use it.

Larkin Co. was in the fortunate position of being able to use in its own business every material recoverable from the sag paste. The business conditions which developed in the fall were sensed by the company before the arrival of the first car of sag paste. This accurate prognostication determined the whole course of procedure. Our immediate object was to salvage the highest value, that is, the block tin, as soon as possible, and dispose of it on the high tin market. With this end in view, we sacrificed the highest possible percentage recovery to speed and volume. The loss of a per cent or two of oil or even of tin, was small compared to the difference between selling tin on a sixty- or on a forty-cent market.

Larkin Co. had available for the sag paste recovery, practically the entire seventh floors of its two adjacent refinery buildings, known to us as L and M Buildings, and portions of the sixth, fifth, and second floors of M building. The carloads of sag paste were received in box cars in L Building, and taken directly from the cars to the weighing scales, from there to the elevator, a total distance of about forty feet. They were then hoisted to the seventh floor and stored or used at once, depending on the conditions under which we were running. We reserved the seventh floor of L building for the storage and opening of the cases.

The covers were pried from the cases with bars and hammers. We planned on cutting the tops of the cases off with power swing saws, but the varying sizes of the boxes, and their unwieldy shape and weight soon showed this to be impractical. The opened cases were placed on four-wheeled trucks, and taken to the girls who removed the tubes from the cartons. This operation was accomplished on the seventh floor of M Building. Here was a 24-inch endless belt, 100 feet long from pulley to pulley. The upper surface of it traveled along a table 30 inches above the floor. This surface was divided into three parallel strips by wooden partitions about 3 inches high. The center strip was $7\frac{3}{4}$ inches and the outer strip

$5\frac{3}{4}$ inches wide. On each side of the belt the table projected 8 inches. The girls worked on each side of the belt. As a girl took a tube from its carton, she placed it on the strip of belt immediately in front of her. It traveled on this strip about two feet, and then went through a little box that had a movable door. Each tube that went through this little box raised the door enough to register on a mechanical counter. The removal of the tubes from the cartons was all piece work and this counter was the method of determining the amount of money each girl earned per day. Beyond the counter was a switch that directed the tube from the outer strip of belting to the center strip, which finally led the tube directly to the crusher. At the right of each girl was a chute into which the girl threw the empty carton. It fell from this onto the upper surface of the returning portion of the belt. It was conveyed by this in an opposite direction from the tube, and near the end of the belt was scraped off by a wooden slide to a hole through the floor. Through this hole, it fell onto the sixth floor directly over a hole from sixth to fifth floor. Here the empty cartons and waste paper accumulated until there were sufficient to bale. They were then shoveled through the hole from sixth to fifth floors directly into the top of the power baler located on the fifth floor. The paper was here baled and then was ready to be lowered to our shipping platform on the first floor. Needless to say there was little delay or accumulation of paper stock. It was sold and shipped as fast as produced.

We left the tube of sag paste on the center portion of the upper belt traveling on its way to the crusher. This machine was the most troublesome to devise of the whole equipment, but as is often the case, when the correct design was finally determined, did the best work and gave the least trouble of any part of the process. We tried first to squeeze the paste from the tubes by passing them through slightly corrugated rolls, but the rolls would not take them. Then we tried to crush them through a Blanchard Mill. This worked magnificently for about ten minutes, then clogged absolutely. The Blanchard Mill consists of two cylinders having large wedge-shaped teeth, and rotating towards each other, the teeth passing between a breaker bar which lies between them. This breaker bar looks very much like an ordinary grate bar. The tin from the tubes built itself up in a solid mass on these teeth, and effectually blocked the machine. While this Blanchard Mill was

being tried out, the corrugations on the crushing rolls were deepened and after the failure of the Blanchard Mill were again installed. They did excellent work on the soft varieties of paste, but their capacities were limited, and they refused absolutely to touch the hard varieties. In the meantime, the whole design of the Blanchard Mill was changed. In place of two rolls only one was used. The teeth which were irregularly spaced were all set on quadrants. In place of the breaker bar an upright strong welded grid of iron was fixed. The teeth then would catch a tube, crush it through the grid and carry the tin fragments down where they were scraped off by strong scrapers set on the lowest point of the circumference of the rotating cylinder. When this mill was installed in place of the corrugated rolls, it proved a complete success. It cleaned itself and stood up under the heaviest duty. Driven by a 15-horse power motor, it would steadily take a stream of tubes three inches high and crush them through itself without missing a single tube or clogging. It was the development of this crusher that made a success of the salvaging operation.

From the crusher, the crushed tubes fell into large iron tumblers 7 feet long x $4\frac{1}{2}$ feet diameter, located on the sixth floor.

Here we must digress from watching the progress of the tubes to describe the chemistry of the two methods of recovery that we used. The paste variety of sag paste melted between 130° to 140° C. into a clear, fairly fluid oil. The paint variety was hardly affected by heat at all, at even 200 or 300° C.—it was still the same sticky, smeary, heavy paint that it was at ordinary temperature. There was no tendency, either, for the oils and zinc oxide to separate. In the case of the paste variety, it was therefore simply necessary to heat the tin and paste to 140° C. when the paste would run free from the tin. This paste, as you remember, consisted of zinc stearate and glycerine fats. It was readily broken up in lead-lined tanks by diluted sulphuric acid yielding a mixture of stearic acid and light colored glycerine fats, an excellent soap stock. The zinc oxide went into the acid solution as zinc sulphate and could be recovered by neutralizing the acid with soda ash.

The paint variety could not be separated from the tubes by heat, but it would form a thin emulsion with a 3 per cent soda ash solution. In that way, it could be washed from the tubes. By carefully controlling the condition, this soda ash emulsion could be broken up and separated into its mixed fats and zinc oxide. The

small amount of soap formed by the action of the soda ash on the free fatty acids in no way lessened the value of the resulting fats for soapmaking.

We left the tubes falling from the crusher into the tumbler. When these tubes had nearly filled the tumbler, the stream of tubes was diverted. The manhole of the tumbler closed tight and the fat was separated from the tubes. If the paste variety was being treated, steam was admitted to the tumbler through a trunnion until a pressure of 40 lbs. was obtained. The tumbler was then rotated 10 minutes and the melted fat blown out through stop cocks located in the opposite side of the tumbler from the manhole. Three repetitions of this process removed practically all the fat from the tubes. The melted fat was run to the lead-lined tanks on the fifth floor. These tanks were the ones we regularly use to break up foots. If the paint variety was being treated a solution of 3 per cent soda ash was pumped into the tumbler, enough steam was admitted to boil the solution, the tumbler was rotated as before and the resulting thin emulsion drawn off. Four soda ash washes completed the operation. The soda ash emulsion was pumped to agitation tanks which we ordinarily use for refining vegetable oils. In these the emulsion was broken. The zinc oxide sludge was dropped to the filter presses on the floor below and the clear fat run to the fat storage tanks.

After the fat or emulsion was removed from the tumbler the manhole was opened and the tumbler rotated for three minutes. This was sufficient to dump all the tin into the pan below the tumbler. The tin was then shoveled into an inclined chute where it fell by gravity to the tin storage bin located in our still room on the second floor of M building.

In the still room we erected an oil-fired melting furnace. This was run by our regular still room operators. The tin was then melted and cast into one hundred pound pigs. These pigs analyzed on the average between 98 and 99 per cent pure tin. They were contaminated with zinc. This zinc was due to two causes, first from the reduction of zinc oxide and second from the presence of some brass chips on the tubes. We might have removed both of these causes had we not decided that it was more profitable to get volume quickly, than quality slowly.

The first carloads of sag paste arrived while this Society was enjoying its delightful Canadian meeting. What a contrast, the

chaos of dirty, greasy boxes, bags and loose tubes was to the majesty and splendor of the Canadian woods! We allowed ourselves one hundred days to do the job and calculated that we must reach a maximum output of ninety thousand tubes per day by the end of that period. We actually obtained an output of over one hundred and ten thousand tubes per day, and the saddest part of it all was that just as everything was going smoothly the job was over. We wished then that we had had a hundred million tubes to salvage.

STUDIES IN EVAPORATOR DESIGN. IV

Experimental Data for Horizontal Tube Evaporator Showing Relation Between Hydrostatic Head, Temperature Drop and Heat Transmission—Ratio of Corrected Coefficients for Two Different Temperature Drops is Constant for All Levels

By W. L. BADGER

Read at the New Orleans Meeting, December 7, 1920

This paper presents two curves showing the relation between hydrostatic head and heat transmission in a horizontal tube evaporator. These two curves were determined at the same boiling point, but with a different steam temperature for each curve; thereby furnishing means for determining the relation between hydrostatic head, temperature drop and heat transmission.

So far as the writer has been able to determine, no systematic experimental work has been done on horizontal tube evaporators. There are scattered tests of horizontal tube evaporators available, but they are all reports of isolated tests on evaporators in actual plant operation, and are therefore not available for systematic study. The previous literature regarding the effect of hydrostatic head on heat transmission and regarding the effect of temperature drop on heat transmission has been discussed elsewhere.[1]

Description of Apparatus and Method of Procedure

These tests were run in the horizontal tube evaporator of the Evaporator Experiment Station at the University of Michigan, which has been described in detail.[2] Briefly, the evaporator body is $25\frac{3}{4}$ inches wide inside and, in these tests, it was 8 feet high inside. It was equipped with 156 steel tubes $\frac{7}{8}$ inch in outside diameter by

[1] "Studies in Evaporator Design"—I, II, III and IV, *Chem. & Met. Eng.*, vol. 23, Nos. 6, 7, 9 and 12, pp. 237, 281, 390 and 569, Aug. 11, 18, and Sept. 1 and 29, 1920.

[2] *Chem. & Met. Eng.*, vol. 23, No. 4, p. 159, July 28, 1920.

$\frac{1}{16}$-inch wall, with an effective length of $46\frac{1}{4}$ inches, making a net heating surface on the wet side of 0.883 square foot per tube. The total heating surface was therefore 137.75 square feet, or 12.795 square meters. The arrangement of the tubes is shown in Fig. 1. In calculating the heating surface, no allowance was made for the tube sheets, which are of cast iron, $1\frac{1}{4}$ inches thick. The tubes are secured in these tube sheets by the standard Swenson tube packing plate (see Fig. 2). When tubes of this size with their centers $1\frac{5}{8}$ inches apart are so secured, the pressure of the packing plate results in a spreading of the gaskets until they unite in a practically continuous sheet of rubber, perhaps $\frac{1}{8}$ inch thick. The packing plates themselves are 1 inch thick and form a continuous sheet. This combination of $2\frac{1}{4}$ inches of cast iron and $\frac{1}{8}$ inch of rubber offers so much resistance to heat transmission as compared to the $\frac{1}{16}$ inch of steel in the tubes proper that it was considered reasonable to omit the tube sheets entirely. In this experimental evaporator the tube sheets are very large, and consequently in this set of experiments a large part of the tube sheet was blanked off. In blanking off holes not in use, the same gaskets and packing plates were used as were used in securing tubes, so that there is no need to consider the upper part of the tube sheets as being a part of the heating surface.

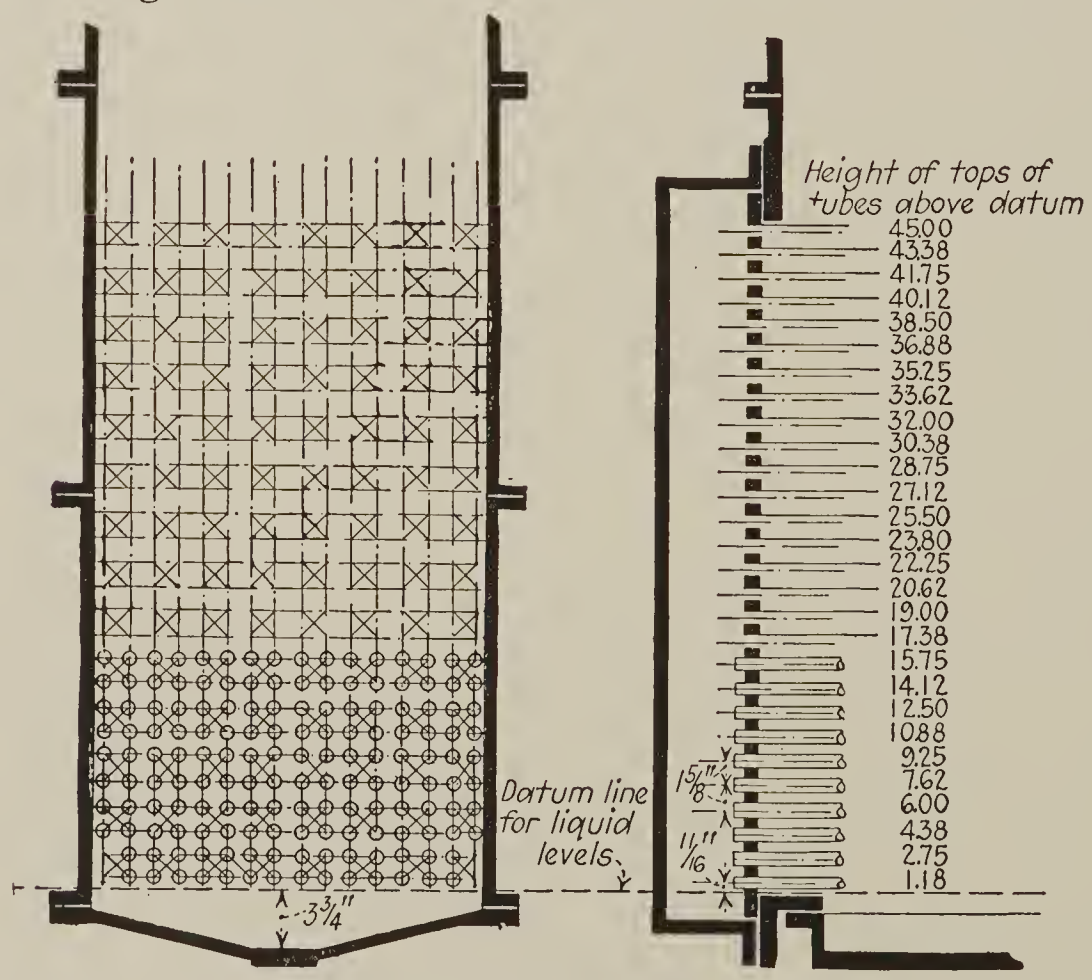


FIG. 1. Arrangement of Tubes in Experimental Evaporator

Air was vented from the top of the front steam chest into the vapor space; and from the bottom of the front steam chest through the condensate receiver and back to the vapor space. Condensed water was taken from the front steam chest only.

When the evaporator was boiling smoothly and conditions seemed uniform, at a signal from the recorder the level of condensate in the receiver was marked, and readings of all temperatures and pressures were begun at once. Readings were taken every two minutes until a sufficient amount of condensed water had accumulated; or in the case of runs at high ratings, until at least ten or twelve sets of readings had been taken. At a signal from the recorder the time was again noted and the amount of condensed water again marked. The evaporator was connected to another receiver, and as soon as conditions had become uniform the next run was started. This usually involved a lapse of five to seven minutes, during which time the evaporator was kept boiling and the conditions kept as constant as possible. In series T there was but one break. Runs 128A, 151B and 259 were made without a shutdown, and then runs 129A, 152B and 260 were also made consecutively. In series U runs 130A–I, –II and –III were made consecutively. There was then a break until the next day, when runs 153B, 154B, 261 and 262 were made consecutively. There was another break, and runs 155B, 156B and 131A were made.

Methods of Measurement and Accuracy of Results

Time was measured with an ordinary watch, and it is probably correct to within ± 2 seconds. The vacuum was controlled by the automatic vacuum regulator described in a previous paper[3] and usually did not vary over ± 2 mm. during a test. Therefore the probable error of the average for a test is very small (less than ± 0.1 mm.). Temperatures of the vapor space were not read systematically, but when read they came so near to the temperature calculated from the vacuum as to indicate no constant error in the manometer greater than ± 1 mm. (or ± 0.13 deg. C. at 60 deg.). In a previous paper[4] there is a discussion of the reasons for preferring temperature calculated from vacuum as the temperature of the boiling liquid rather than temperature determined by a thermometer inserted into the machine. It should be noted that in calculating on

[3] *Chem. & Met. Eng.*, vol. 23, No. 4, p. 161, July 28, 1920.

[4] *Chem. & Met. Eng.*, vol. 23, No. 6, p. 241, Aug. 11, 1920.

the basis of the temperature corresponding to the vacuum the results are in terms of apparent temperature drop and are therefore apparent coefficients.

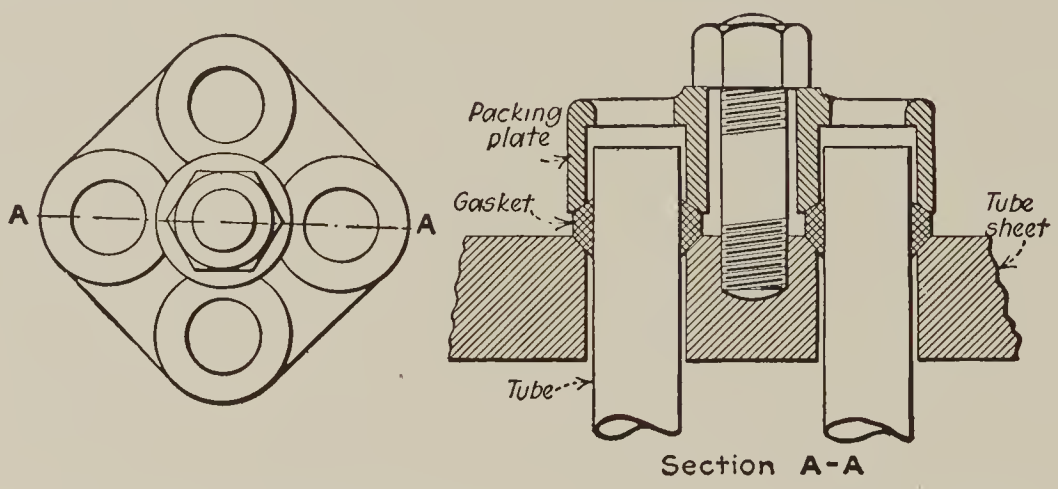


FIG. 2. Tube Packing Plate Showing Method of Securing Tubes

TABLE I

STEAM TEMPERATURES IN BACK AND FRONT STEAM CHESTS DURING SERIES T
In Degrees Centigrade

Run No.	Back Steam Chest.			Front Steam Chest.			Drop in Satn. Temp. VII.
	Temp. from Therm. I.	Temp. from Press. II.	Superheat III.	Temp. from Therm. IV.	Temp. from Press. V.	Superheat VI.	
128A I...	115.82	100.07	15.75	101.85	100.08	1.77	−0.01
II..	115.80	100.04	15.76	103.26	100.06	3.20	−0.02
III.	114.18	100.01	14.17	104.77	100.07	4.70	−0.06
151B I...	112.35	99.91	12.64	103.13	99.94	3.19	−0.03
II..	112.91	100.01	12.90	103.48	100.38	3.10	*−0.37
III.	114.08	100.08	14.00	103.39	100.06	3.33	+0.02
129A I...	113.64	100.14	13.50	102.23	100.12	2.11	+0.02
II..	114.88	99.96	14.92	102.81	100.02	2.79	−0.06
III.	114.45	100.00	14.45	102.85	99.95	2.90	+0.05
259 I...	111.10	100.01	11.09	103.23	99.99	3.24	+0.02
II..	111.28	100.00	11.28	103.25	99.99	3.26	+0.01
III.	110.52	100.04	10.48	103.32	99.98	3.34	+0.06
152B I...	114.21	99.95	14.26	102.29	99.93	2.36	+0.02
II..	115.69	100.03	15.66	102.39	100.02	2.37	+0.01
III.	115.89	100.05	15.84	102.52	100.03	2.49	+0.02
260 I...	116.80	100.07	16.73	102.55	100.01	2.54	+0.06
II..	115.55	100.03	15.52	102.28	100.00	2.28	+0.03
III.	115.62	100.03	15.59	101.35	99.98	1.37	+0.05
Average..	114.16	100.02	14.14	102.79	100.01	2.78	+0.01

NOTE.—Column III = Column I − Column II. Column VI = Column IV − Column V. Column VII = Column II − Column V.

* Omitted.

Steam pressures were measured by mercury manometers attached directly to the steam chests. Long experience with metal piping (both ordinary iron pipe and fittings and seamless copper tubing) has led us to distrust manometers for steam which are any great distance from the point at which the pressure is to be measured. We therefore abandoned the idea of manometers on an instrument board. A special brass stuffing box was screwed into a tapped hole in the steam chest covers. Glass manometer tubes were made with the end of one arm bent horizontal to enter this stuffing box. Water slowly accumulated in the steam side, but it was measured at each reading and allowed for in the calculations. The average of the manometer readings is probably accurate to less than 1 mm. This is equivalent to ± 0.04 deg. on the saturation temperature for series T, and ± 0.05 deg. for series U.

TABLE II

STEAM TEMPERATURES IN BACK AND FRONT STEAM CHESTS DURING SERIES U
In Degrees Centigrade

Run No.	Back Steam Chest.			Front Steam Chest.			Drop in Satn. Temp. VII.
	Temp. from Therm. I.	Temp. from Press. II.	Super-heat III.	Temp. from Therm. IV.	Temp. from Press. V.	Super-heat VI.	
261 I...	108.13	89.96	18.17	91.40	89.96	+1.44	0.00
III.	108.73	89.95	18.78	91.39	89.86	+1.53	+0.09
262 I...	107.48	90.15	17.33	91.32	89.97	+1.35	+0.18
II..	107.82	89.91	17.91	91.07	89.93	+1.14	−0.02
154B I...	110.73	89.99	20.74	91.15	89.95	+1.20	+0.04
II..	110.15	89.94	20.21	91.64	89.95	+1.69	−0.01
130A I...	111.15	90.03	21.12	90.47	90.05	+0.42	−0.02
II..	111.26	89.81	21.45	91.75	89.75	+2.00	+0.06
III.	110.84	89.99	20.85	92.02	90.01	+2.01	−0.02
131A I...	105.60	89.99	15.61	90.06	90.04	+0.02	−0.05
II..	104.97	89.85	15.12	89.89	89.93	−0.04	−0.08
155B II..	104.16	89.81	14.35	88.88	89.69	−0.81	+0.12
III.	104.01	90.03	13.98	89.43	90.01	−0.58	+0.02
156B I...	104.23	90.01	14.22	89.83	90.01	−0.18	0.00
153B I...	109.81	89.90	19.91	89.99	89.88	+0.11	+0.02
Average..	107.94	89.95	17.99	90.69	89.93	+0.76	+0.02

NOTE.—Column III = Column I − Column II. Column VI = Column IV − Column V. Column VII = Column II − Column V.

Steam temperatures, because of the accessibility of the steam chests of a horizontal tube evaporator, can be ascertained much more satisfactorily than in the vertical type evaporator. Four calibrated thermometers were inserted in each steam chest, distributed over the part opposite the ends of the tubes in use. The averages of these thermometer readings are given in Tables I and II. (The "back" steam chest is the one in which the steam enters.) The probable error of the average temperature in the back steam chest was about ± 0.3 deg. Condensate temperature was measured in the condensate line about 3 feet from the steam chest. The error of this reading may have been ± 0.2 deg.

Heat Available

It will be seen from the data of these tables that there was considerable superheat in all the runs. This is because high-pressure steam was used and throttled at the evaporator. The heat transmitted through the heating surface per kg. of steam condensed is, therefore: (1) Heat given up as superheat in cooling to saturation temperature. (2) Latent heat of condensation. (3) Sensible heat given up by condensed water in cooling from saturation temperature to the temperature at which it left the evaporator. (4) Heat given up in cooling from the temperature of the back steam chest to the temperature of the front steam chest, by steam bled through vents or condensed by radiation in condensate lines and condensate receivers. Of these, No. 4 may be omitted as too small to consider. The other items may be readily calculated. In this respect the work on the horizontal tube evaporator is more definite than on the vertical tube evaporator. The superheat may be in error by ± 0.15 cal.; the latent heat by ± 0.03 cal.; and the sensible heat by ± 0.2 cal. Since the total heat given up per kg. of steam condensed was about 550 cal., the greatest probable error would be ± 0.4 cal., or 0.08 per cent.

It is interesting to note that the temperature drop from the back steam chest to the front steam chest (calculated from pressure) was of the order of a few hundredths of a degree. In most cases the drop is toward the front steam chest, as would be expected. In series T, the pressure drop in 151B–II is evidently in error. Omitting this, there is no difference between the two steam chests over 0.18 deg. in either series. The average difference is + 0.01 deg. in series T and + 0.02 deg. in series U.

Calculation of Apparent Temperature Drop

In calculating the apparent temperature drop there are complications due to the presence of superheat. In order to handle the calculations it will be assumed that the processes are as follows: First the steam is cooled to the saturation temperature, giving up its superheat. Next it is condensed to a liquid at a temperature corresponding to the mean of the pressures in the front and back steam chests. Finally, the condensate is cooled from this temperature to the temperature at which it leaves the evaporator. Under these assumptions the following formulation holds: (See Fig. 3.)

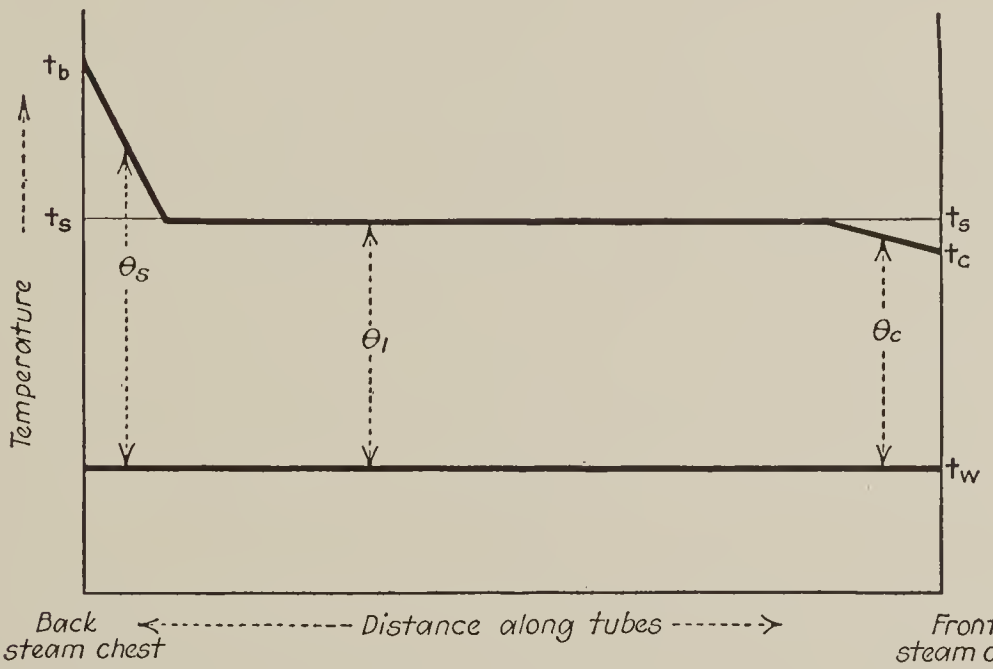


FIG. 3. Temperature Gradient in the Horizontal Tube Evaporator

t_w, temperature of boiling liquid; t_b, temperature of superheated steam entering tubes from back steam chest; t_c, temperature of saturated steam in tubes; t_s, temperature of condensed water.

t_b = temperature of back steam chest from thermometers.
t_f = temperature of front steam chest from thermometer.
t_s = temperature of saturated steam corresponding to mean of the pressures of front and back steam chests.
t_c = temperature of condensed water.
t_w = temperature corresponding to vacuum.
θ_s = mean temperature difference during transfer of superheat.
θ_l = mean temperature difference during transfer of latent heat.
θ_c = mean temperature difference during transfer of sensible heat of condensate.
H_s = heat as superheat in calories per kg.
H_l = latent heat in calories per kg.

H_c = sensible heat recovered from 1 kg. of condensate.
θ_m = mean apparent temperature drop.
Then

$$\theta_s = \frac{(t_b - t_w) + (t_s - t_w)}{2} \tag{1}$$

$$\theta_l = t_s - t_w \tag{2}$$

$$\theta_c = \frac{(t_s - t_w) + t_c - t_w}{2} \tag{3}$$

$$\theta_m = \frac{\theta_s H_s + \theta_l H_l + \theta_c H_c}{H_s + H_l + H_c} \tag{4}$$

In equations 1 and 3 the arithmetical mean has been used instead of the logarithmic mean. This is because H_s and H_c are so small that the error so made in θ_s and θ_c is without significance in the final result.

TABLE III

CALCULATION OF MEAN APPARENT TEMPERATURE DROP (θ_m)

$$\theta_m = \frac{H_s\theta_s + H_l\theta_l + H_c\theta_c.}{H_s + H_l + H_c}$$

Run.	Series T.			Series U.		
	128A–I.	259 III.	260 I.	130A–I.	261 II.	155B–III.
w	75.02	75.08	75.10	75.20	74.96	74.98
b	115.82	110.52	116.80	111.15	108.73	104.01
t_s	100.08	100.01	100.04	90.04	89.91	90.02
Superheat	15.74	10.51	16.76	21.11	18.82	13.99
H_s	7.66	5.12	8.15	10.15	9.04	6.72
H_l	538.65	538.69	538.68	544.88	544.96	544.89
H_c	0.34	0.19	0.20	0.71	0.90	1.01
$H_s + H_l + H_c$	546.65	544.00	547.03	555.74	554.90	552.62
θ_s	32.93	30.18	33.32	25.40	24.36	22.03
θ_l	25.06	24.93	24.94	14.84	14.95	15.04
θ_c	24.89	24.83	24.84	14.48	14.50	14.54
$H_s\theta_s$	252.24	154.52	271.56	257.81	220.21	148.04
$H_l\theta_l$	13,498.57	13,429.54	13,434.68	8,086.02	8,147.15	8,195.15
$H_c\theta_c$	8.46	4.72	4.97	10.28	13.85	14.69
$H_s\theta_s + H_l\theta_l + H_c\theta_c$.	13,759.27	13,588.78	13,711.21	8,354.11	8,380.41	8,357.88
θ_m	25.17	24.98	25.07	15.03	15.10	15.12
$\theta_m - \theta_l$	+0.11	+0.05	+0.13	+0.19	+0.15	+0.08

The above method of calculation was applied to a number of runs. The results of a few, selected because they represent ex-

tremes, appear in Table III. As will be seen, H_s and H_c are so small in comparison with H_l that they are not significant. In view of the amount of calculating saved, θ_l has been used in all the data of this paper instead of θ_m. The total heat available from 1 kg. of steam condensed was, however, determined by taking the sum of H_s, H_l and H_c. Hence the values used for θ may be in error by not over $\pm$ 0.2 deg. due to this method of calculation. As stated above, t_w has an error of $\pm$ 0.13 deg., and t_s $\pm$ 0.05 deg. Therefore the final values for θ may have a maximum error of $\pm$ 0.4 deg. or $\pm$ 2.6 per cent, in series U and $\pm$ 1.6 per cent in series T.

In all cases temperatures were read to tenths of degrees and pressures to millimeters of mercury. In all calculations temperatures were carried to hundredths of degrees and pressures to tenths of millimeters. The final results were rounded off to the nearest whole number for the values of K and U. So far as the probable error of any of the determinations goes, the final result is probably accurate to 1 to 2 per cent. However, the possibility of systematic errors makes us doubtful whether we should assign a greater accuracy than $\pm$ 50 to any figures for K. Duplicates can be obtained closer than this.

Results

The data for the two series are given in Table IV and are plotted in Fig. 4. From the data of these tables it would seem that in runs 131A, 155B and 156B, there was not enough venting from the front steam chest, so that some air accumulated at that point. In series T steam pressures throughout were above atmospheric pressure and therefore it was easy to keep the steam chests free of air.

Effect of Superheat

The question on the effect of the presence of superheat is one which has been discussed many times in the literature. A few scattered tests are available to show the effect of superheat, but as a general thing they are not systematic and lead to contrary conclusions. In no case have tests been carried out where the total heat transmitted was entirely or even largely superheat.

The writer's point of view is as follows:

The amount of heat in superheat under conditions at which we work is so small a proportion of the total heat transmitted that most of the heating surface is actually transmitting heat from saturated steam. The small part of the heating surface which transmits

heat from superheated steam may be working at a rate which is relatively very low, but this part of the surface is too small to affect the results appreciably.

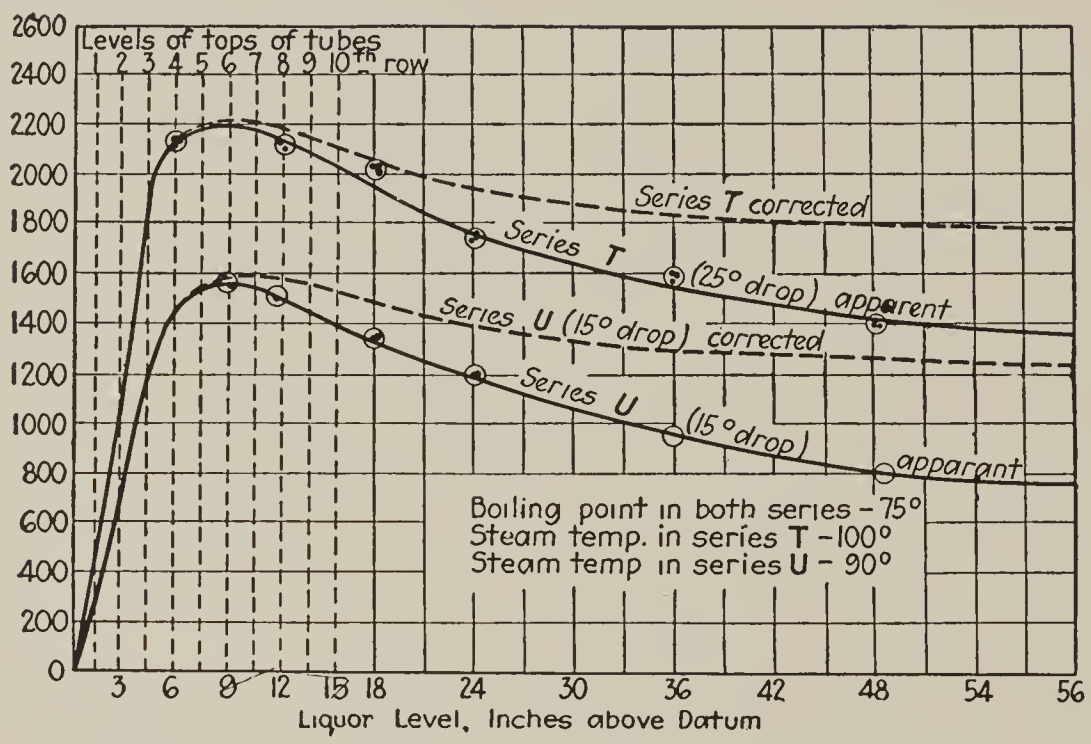

Levels of tops of tubes
1 2 3 4 5 6 7 8 9 10th row
Series T corrected
Series T
(25° drop) apparent
Series U (15° drop) corrected
Series U
(15° drop)
apparent
Boiling point in both series - 75°
Steam temp. in series T - 100°
Steam temp in series U - 90°
Liquor Level, Inches above Datum

FIG. 4. Apparent and Corrected Heat Transmission Coefficients for Two Different Temperature Drops (Series T and U)

It will be noted that these statements are purely qualitative. For the present we prefer not to attempt to deal in numerical statements. By a rearrangement of the steam lines in the experiment station it is now possible to operate the horizontal tube evaporator on steam of pressure low enough so that there is no appreciable superheat, even in the steam chest. By a comparison with the runs here reported we hope to confirm the above qualitative statements with quantitative data in the near future.

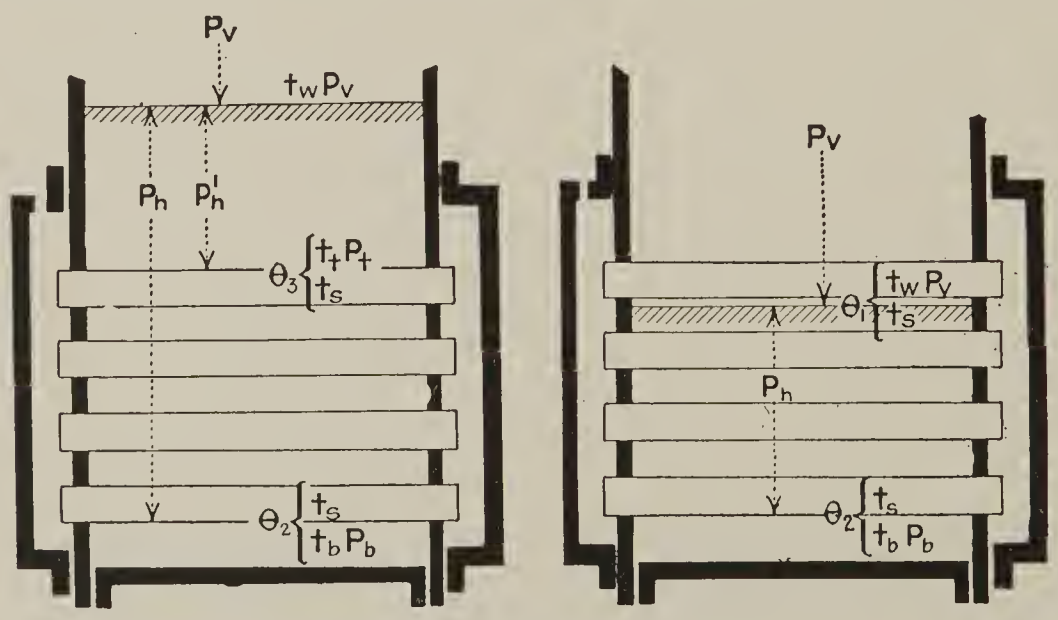


FIG. 5. Illustration of Method of Correcting Heat Transmission Coefficients for Effect of Hydrostatic Head

TABLE IV.

HEAT TRANSMISSION DATA OBTAINED IN SERIES T AND U.

Run.	Level.	Time Min.	Abs. Vac.	Corres. Temp.	Abs. Steam Press.	Series T Corres. Temp. Steam.	Actual Temp. Steam.	Super-heat.	Cond. Temp	Cond. Lb.	θ	K	U
128A I	6.03	10.0	289.3	75.02	762.1	100.08	115.82	15.76	99.74	457.7	25.06	2,123	434.8
128A II	5.92	16.0	289.4	75.03	761.3	100.05	115.80	15.75	99.79	740.5	25.02	2,150	440.3
128A III	6.00	15.0	290.3	75.11	760.2	100.01	114.18	14.17	99.56	546.1	24.90	2,138	437.8
151B I	12.41	16.0	290.5	75.12	758.5	99.94	112.55	12.61	99.65	719.1	24.82	2,100	430.0
151B II	12.93	14.0	289.4	75.03	770.5	100.38	112.41	12.03	100.07	650.4	25.35	2,124	434.9
151B III	12.25	16.0	289.9	75.07	761.9	100.07	114.08	14.01	99.85	731.6	25.00	2,123	434.8
259 I	18.10	16.0	289.9	75.07	760.1	100.00	111.10	11.10	99.79	694.4	24.93	2,016	412.8
259 II	17.87	16.0	290.0	75.08	759.8	99.99	111.28	11.29	99.79	698.1	24.91	2,028	415.2
259 III	18.03	16.0	290.0	75.08	760.2	100.01	110.52	10.51	99.82	700.2	24.93	2,031	415.9
129A I	23.80	18.0	289.7	75.06	763.5	100.13	113.64	13.51	99.89	672.7	25.07	1,729	354.1
129A II	23.97	16.0	289.4	75.03	759.8	99.99	114.88	14.89	99.87	599.9	24.96	1,745	357.4
129A III	24.10	20.0	290.2	75.10	759.5	99.98	114.45	14.47	99.89	756.8	24.88	1,766	361.6
152B I	35.90	20.0	289.4	75.03	758.4	99.94	114.21	14.27	99.72	676.0	24.91	1,575	322.5
152B II	36.23	20.0	289.6	75.05	760.7	100.03	115.69	15.66	99.71	684.0	24.98	1,592	326.1
152B III	36.03	20.0	289.3	75.03	761.2	100.04	115.89	15.85	99.80	688.2	25.01	1,600	327.6
260 I	47.97	16.0	290.2	75.10	761.1	100.04	116.80	16.76	99.84	482.2	24.94	1,406	287.9
260 II	48.05	20.0	290.8	75.15	760.4	100.01	115.55	15.54	99.92	604.9	24.86	1,414	289.5
260 III	48.18	16.0	287.8	74.90	760.1	100.00	115.62	15.62	99.92	483.2	25.10	1,398	286.3
Average	.....	.....	289.7	75.06	.....	100.04	.....	.....	.....	.....	24.98	.....	.....

TABLE IV—*Continued*

Series U.

153B I	6.17	24.0	290.7	75.14	523.8	89.90	109.81	19.91	88.73	438.0	14.76	1,461	299.2
154B I	9.00	20.0	288.9	74.99	525.1	89.96	110.73	20.77	89.13	400.9	14.97	1,582	324.0
154B II	9.28	18.5	284.9	74.66	524.8	89.95	110.15	20.20	88.97	370.7	15.29	1,549	317.1
130A I	12.10	20.0	291.4	75.20	526.6	90.04	111.15	21.11	89.33	378.5	14.84	1,508	308.8
130A II	11.95	20.0	288.8	74.98	521.4	89.78	111.26	21.48	89.02	379.5	14.80	1,516	310.5
130A III	12.00	20.0	293.5	75.37	525.9	90.00	110.84	20.84	89.47	413.9	14.63	1,671	342.2
261 I	17.87	20.0	289.6	75.05	525.0	89.96	108.13	18.17	89.12	340.0	14.91	1,345	275.4
261 II	17.97	20.0	288.5	74.96	524.0	89.91	108.73	18.82	89.01	342.4	14.95	1,351	276.7
262 I	23.97	20.0	288.0	74.92	525.7	89.99	107.48	17.49	89.16	340.4	15.07	1,190	243.7
262 II	24.08	24.0	285.9	74.74	524.2	89.92	107.82	17.90	88.93	368.7	15.18	1,194	244.5
155B II	35.95	21.0	286.4	74.76	520.8	89.75	104.16	14.41	88.69	270.1	14.99	1,009	206.7
155B III	35.95	20.0	288.8	74.98	526.2	90.02	104.01	13.99	89.01	230.2	15.04	899	184.2
156B I	35.97	20.0	287.2	74.85	527.8	90.10	104.23	14.13	89.02	239.9	15.25	925	189.4
131A I	48.08	24.0	290.5	75.12	524.9	89.95	105.60	15.65	88.98	255.6	14.83	845	173.1
131A II	49.30	24.0	289.4	75.03	522.2	89.82	104.97	15.15	88.68	231.6	14.79	768	157.3
Average	.....	.....	288.8	74.98	.....	89.94	.....	.....	.....	.....	14.96	.....	.....

The data of Table IV are apparent heat transmission coefficients —that is, they are determined by dividing the total heat transmitted by the apparent temperature drop. They may be corrected for effect of hydrostatic head by the following method. (See Fig. 5.)

TABLE V

CALCULATION OF HYDROSTATIC HEAD CORRECTIONS FOR SERIES T AND U

Level.	Series T. Levels Below Top of Tubes.		Series U.	
	6 In.	12 In.	6 In.	12 In.
H_a	7.874 sq. m.	2.6247	7.874	2.625
H_b	4.9213	10.171	4.920	10.169
t_b	75.90	76.77	75.84	76.81
θ_2	24.14	23.27	14.12	13.23
θ_4	24.56	24.12	14.54	14.10
θ_{mh}	24.82	24.30	14.80	14.27
Apparent K	2,140	2,125	1,425	1,500
Correct K	2,153	2,182	1,440	1,573
	t_s = 100.04° C. t_w = 75.06° C.		t_s = 89.94° C. t_w = 74.98° C.	
	θ_1 = 24.98° C.		θ_1 = 14.96° C.	

Levels Above Top of Tubes.

Level.	18 In.	24 In.	36 In.	48 In.	18 In.	24 In.	36 In.	48 In.
t_b	77.64	78.45	80.01	81.49	77.53	78.36	79.92	81.40
t_t	75.39	76.27	77.95	79.53	75.32	76.20	77.89	79.46
θ_2	22.40	21.59	20.03	18.55	12.41	11.58	10.02	8.54
θ_3	24.65	23.77	22.09	20.51	14.62	13.74	12.05	10.48
θ_{mh}	23.53	22.68	21.06	19.53	13.52	12.66	11.04	9.51
Apparent K	1,930	1,765	1,550	1,400	1,345	1,190	960	810
Correct K	2,049	1,940	1,840	1,792	1,488	1,406	1,302	1,275

In addition to the nomenclature given above under the calculation of temperature drop, the following are needed:

p_v = absolute pressure in vapor space.
p_h = hydrostatic head on bottom of heating surface.
p'_h = hydrostatic head on top of heating surface.
p_b = total pressure on bottom of heating surface.
p_t = total pressure on top of heating surface.
t_b = temperature corresponding to p_b.
t_t = temperature corresponding to p_t.

For those cases where the liquid is above the top of the heating surface we have the following:

θ_1 = apparent temperature drop = $t_s - t_w$.
$p_t = p_v + p'_h$.
$p_b = p_v + p_h$.
$\theta_2 = t_s - t_b$ = temperature drop at bottom of heating surface.
$\theta_3 = t_s - t_t$ = temperature drop at top of heating surface.
θ_{mh} = mean temperature drop corrected for effect of hydrostatic head $= \dfrac{\theta_3 + \theta_2}{2}$.

For those cases where the liquor level is below the top of the heating surface the formulation becomes:

p'_h = 0, hence $t_t = t_w$.
$\theta_2 = t_s - t_b$ = temperature drop at bottom of heating surface.
H_a = heating surface above liquor level.
H_b = heating surface below liquor level.
$\theta_4 = \dfrac{\theta_1 + \theta_2}{2}$ = mean temperature drop over submerged part of heating surface.

$$\theta_{mh} = \frac{H_a\theta_1 + H_b\theta_4}{H_a + H_b}$$

There are certain errors made in the above corrections of which the writer is aware but which do not introduce enough error to be significant. In particular, the mean temperature drop is, of course, not the arithmetical mean of the temperature drops at top and bottom of heating surface, but is determined by some other function which involves the relation between the vapor pressure of water and temperature. Averages obtained by graphic integration of the vapor pressure curve for water over the pressure ranges involved in these hydrostatic head corrections showed differences from arithmetical mean of only 0.02 to 0.03 deg.

TABLE VI

RATIO OF CORRECTED VALUES, SERIES U, TO CORRECTED VALUES, SERIES T

Level, In.	Ratio U : T
10	0.721
12	0.721
18	0.725
24	0.724
36	0.708
48	0.712

The great similarity of the curves, series U and series T, is at once evident; and some search was made for a quantitative relation. Table VI showing the ratios of the corrected values in the two series indicates at once a very useful relation—namely, that if the ratio of heat transmission coefficients for different temperature drops is determined for a given evaporator at any one liquor level, the same ratio may be used for other liquor levels with an accuracy far greater than that now involved in any other part of the design.

Conclusions

The following conclusions must for the present be considered as indicating tendencies only, and must be applied with caution to evaporators differing much in design from the one in which they are determined.

1. In horizontal tube evaporators the maximum capacity occurs when the tubes are from half to two-thirds submerged.

2. The maximum capacity is reached at levels nearer the top of the heating surface as the apparent temperature drop becomes smaller.

3. The maximum apparent heat transmission coefficient is 105 to 108 per cent of the heat transmission coefficient where the liquor level is at the top of the heating surface.

4. The ratio of corrected heat transmission coefficients for two different temperature drops is constant for all levels above the optimum.

All of the work reported in this paper was done with funds supplied by the Swenson Evaporator Co., to which the writer wishes to express his indebtedness for permission to publish the result.

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THE MOTOR FUEL PROBLEM

By E. H. LESLIE

Read at the Detroit Meeting, June 21, 1921

The motor fuel problem, which may be summarized in the three questions — What will be the fuels of the future, will the fuels be obtainable at a reasonable cost, and will changes in present methods of utilization be necessitated — is one of the most important with which we are faced. Consideration of the facts will make it clear that we cannot depend upon present sources and methods indefinitely.

Primarily involved in the readjustments which must be made are two great industries: that of producing, transporting, refining, and marketing petroleum and its products; and that of manufacturing automobiles, trucks, tractors, airplanes, and stationary engines. But it is the public, which has come to depend upon the use of automotive appliances, that will suffer if the future motor fuel supply is not adequate.

The existence of a motor fuel problem has been recognized somewhat generally for only three years, even by the majority of those most immediately concerned. Some leaders in the oil industry still ridicule the idea of a petroleum shortage. Possibly they may be pardoned if they are carried away by their own successes in production. The atmosphere of an oil-boom center is not conducive to obtaining a proper perspective for viewing the petroleum situation as a whole. Possibly, also, business reasons may make it expedient to paint a very rosy picture of the future. And, further, why should a large and well established producer of petroleum and its products be concerned as to the future? It is clear that a shortage of oil will lead to higher prices for the crude products and for the finished products, and that this increased return will not be offset by a similar increase in the cost of production or manufacture.

On the other hand it is evident that the automotive industry is in an entirely different position. Its future depends upon the avail-

ability of a cheap fuel of suitable form. It is not surprising then that the Society of Automotive Engineers and the National Automobile Chamber of Commerce have taken the initiative in an effort to coordinate activities of the producer and the consumer of fuels. The first joint meeting between representatives of these organizations and the then newly formed American Petroleum Institute was held on June 4, 1919. The importance of the problem was so obvious that a committee consisting of ten members, five selected by the American Petroleum Institute and five selected jointly by the National Automobile Chamber of Commerce and the Society of Automotive Engineers, was appointed to deal with situations arising from time to time, and to plan constructively for the future. At a joint committee meeting on August 21, 1919, a resolution was adopted urging flexible motor fuel specifications and recommending extensive research work in the fields of production and of utilization.

I do not feel that one should be an alarmist as regards the future supply of motor fuel, but that man is blind who cannot see from the facts that the subject demands the most careful study, both from the standpoint of production and of consumption of fuels.

So many phases of the problem are distinctly within the province of the chemical engineer that it is logical to suggest that this Institute should take a more active interest in the subject than it has in the past. The technology of the refinery, the development of methods for the thermal treatment of oils, the burning of hydrocarbons in the cylinders of an engine, the distillation of oils from shale, the manufacture of alcohol, all are fundamentally within the field of chemical engineering.

In this paper I wish to show how the production of motor fuel has kept pace with the demand, to show what may be expected further from each of those sources of motor fuel that have contributed in increasing the supply, and lastly to venture a few predictions with regard to other sources of fuel that have been of small importance up to this time.

The Growth of the Automotive Industries

The rapid growth of the motor-vehicle industries is shown in Tables I, II, and III.

These are the figures of the National Automobile Chamber of Commerce as reported in "Facts and Figures," the annual statistical review of this organization.

TABLE I

	1899	1904	1909	1914	1919
Capital invested.	$5,769,000	$23,084,000	$173,837,000	$407,730,000	$1,802,302,000
Motor vehicle production ...	3,700,000	21,975,000	127,731,000	569,045,000	1,974,016,000
Value of products	4,748,000	30,034,000	249,202,000	632,831,000	2,506,834,000
Persons engaged in manufacture.....	.....	13,333,000	85,359,000	145,951,000	651,450,000
Wages and salaries.....	1,616,000	8,416,000	58,173,000	139,453,000	813,731,000

TABLE II

PRODUCTION OF PASSENGER CARS AND MOTOR TRUCKS

Year	Passenger Cars	Motor Trucks	Combined Passenger Cars and Motor Trucks
1899.....	3,700	...	3,700
1904.....	21,281	411	21,975
1909.....	127,731	3,255	127,731
1910.....	181,000	....	187,000
1911.....	199,319	10,655	210,000
1912.....	356,000	22,000	378,000
1913.....	461,500	23,500	485,000
1914.....	543,679	25,375	569,045
1915.....	818,618	74,000	892,618
1916.....	1,493,617	90,000	1,583,617
1917.....	1,740,792	128,157	1,868,947
1918.....	926,388	227,250	1,153,637
1919.....	1,657,652	316,364	1,974,016
1920.....	1,473,061	245,322	1,718,383

The figures are those of the N. A. A. C. except for 1920 which is an estimate by John Moody given in his weekly letter of March 3, 1921.

When one considers that only twenty-five years ago there were only four automobiles in the country, one in a circus, another used for exhibitions and two that were looked upon as mechanical freaks the existence of the present total of nine million seems almost unbelievable. The increase in the rate of production has been rapid. In 1914 there were four and one half times as many cars and trucks manufactured as in 1909, and in 1919 three and one half times as many as in 1914. Obviously this rate of growth cannot continue. In fact we must now regard the motor industries as being in a transitional stage of their development. Heretofore a very large

part of the cars passed into the hands of buyers who had never before owned a car. In a few years the larger part of the business will be replacement sales, and the smaller part, which will be roughly proportional to the growth in population of the country, will be new business.

TABLE III

REGISTRATION OF MOTOR VEHICLES

Dec. 31, of the Year	Number of Vehicles
1899	10,000 (estimated)
1904	85,000 "
1909	400,000 "
1910	600,000
1911	677,000
1912	1,010,483
1913	1,253,875
1914	1,711,339
1915	2,445,664
1916	3,512,996
1917	4,983,340
1918	6,146,617
1919	7,558,848
1920	8,932,458

Figures 1899–1913 inclusive from Senate Document 310, 64th Congress, 1st Session, and cited there as being N. A. A. C. dates.

Figures 1914–1919 inclusive from "Facts and Figures" of N. A. A. C.–1920.

Figure for 1920 estimated.

Passenger cars and trucks use between seventy-five and eighty per cent of the gasoline consumed in this country. The other twenty per cent is used in stationary engines, tractors, airplanes, power boats, and for miscellaneous purposes as a solvent. We may expect to see a marked increase in the number of pleasure cars, trucks, tractors, and airplanes, and hence a demand for more fuel.

To summarize, it is evident that the future will require the production of a far larger quantity of motor fuel than is at present available. If it is assumed that the future total number of cars and trucks be stabilized at 13,000,000, that these vehicles consume 75 per cent of the total fuel, and that the exportation of gasoline be the same as at present, the total gasoline requirement will be slightly less than seven billion gallons. The present total consumption and exportation of gasoline is not quite five billion gallons.

The Production of Gasoline

In Table IV statistics are presented covering the production of gasoline in the United States, the imports of gasoline, the domestic consumption of gasoline, the exports of gasoline, and the percentage of gasoline obtained from crude oil. Imports were of little consequence prior to 1915. The consumption is calculated by adding together production and imports, subtracting exports, and in those years for which the statistics are available, correcting the result for the change in stocks during the year. Starting with 1918 the U. S. Bureau of Mines has collected and compiled comprehensive statistics of the oil-refining industry.

TABLE IV

Gasoline Statistics

Year	Production of Gasoline in U. S. (Bbls. of 42 Gallons)	Imports of Gasoline into U. S. (Bbls. of 42 Gallons)	Exports of Gasoline from U. S. (Bbls. of 42 Gallons)	Consumption of Gasoline in U. S. and Insular Possessions. (Bbls. of 42 Gallons)	Per Cent of Gasoline Obtained from Crude Oil
1899..	6,680,000[a]	.....	297,000	6,383,000	..
1904..	6,920,000[a]	.....	594,000	6,326,000	..
1909..	12,900,000[a]	.....	1,640,000	11,260,000	9.3
1914..	34,915,000[a]	.....	4,990,000	29,925,000	17.5
1915..	41,600,000[b]	27,300[e]	6,710,000[e]	34,917,300	18.3
1916..	49,020,960[c]	64,400[e]	8,470,000[e]	40,615,360	18.1
1917..	67,870,150[c]	248,400[e]	9,680,000[e]	58,438,550	21.6
1918..	85,007,450[d]	307,127[d]	13,248,150[d]	74,802,852[f]	26.1
1919..	94,234,690[d]	212,861[d]	8,711,500[d]	82,177,326[f]	26.1
1920..	116,251,110[d]	1,096,812[d]	15,124,940[d]	101,851,840[f]	28.3

[a] Data from Senate Document 310, 64th Congress, 1st Session, Compiled by Bureau of Census.

[b] Estimated for Senate Document 310, 64th Congress, 1st Session, by U. S. Geological Survey.

[c] Figures of U. S. Geological Survey.

[d] Figures of U. S. Bureau of Mines.

[e] Figures of the U. S. Bureau of Foreign and Domestic Commerce.

[f] These figures are corrected for changes during the year in refined stocks on hand.

The increase in the production of gasoline is little less than marvelous. In the five-year period 1915–1920 the output nearly trebled.

But the registration of motor vehicles increased even more, for on December 31, 1920, there were 3.65 times as many vehicles registered as on December 31, 1915. The race is "nip and tuck" with gasoline able, so far, to "keep even with the pole horse."

The ratio between gasoline production and motor-vehicle registration, and between gasoline consumption and vehicle registration, in shown in Table V.

TABLE V

Year	Barrels of Gasoline Produced per Motor Vehicle in Operation.	Barrels of Gasoline Consumed per Motor Vehicle in Operation.
1915	17.0	14.3
1916	13.9	11.5
1917	13.6	11.7
1918	13.8	12.1
1919	12.5	11.9
1920	13.0	11.4

The proportion of the total gasoline that is consumed by motor vehicles lies between 75 and 80 per cent, so that to obtain an approximate idea as to the actual annual gasoline consumption per vehicle it is necessary to multiply the figures given in the second column by 0.75. Undoubtedly the use of each vehicle is greater today than it was a few years ago. Hence the fact that the barrels of fuel consumed per vehicle per year has been nearly constant since 1916 shows that the fuel is more effectively utilized today than it was a few years ago.

I have already mentioned that a fuel problem has been recognized for about three years. To increase the proportion of gasoline obtained from crude oil to 20 per cent was fairly easy. In Figure 1 a curve is given showing actual gasoline production, and another showing what the production would have been if the gasoline yield had been 20 per cent of the crude by volume. The ordinates between the curves AB and DB represent gasoline that could have been fairly easily produced. The ordinates between lines BE and BC represent quantities of gasoline produced with difficulty and only because of the great demand for the product. The point B at which the curves cross may be taken as showing the time when the gasoline problem became real enough to attract general attention. (Notc—A graphical showing similar to Figure 1 has been given by

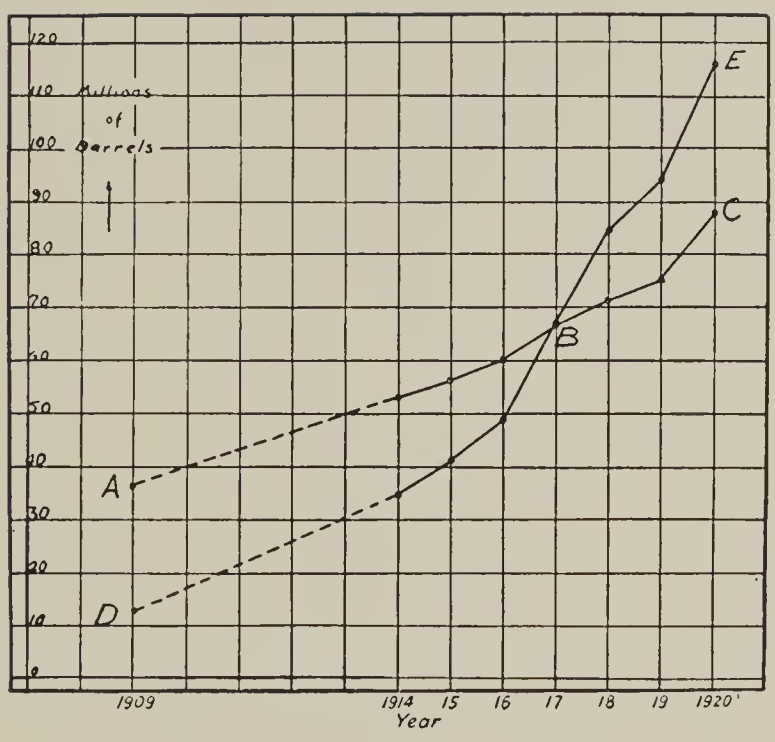

FIG. 1.

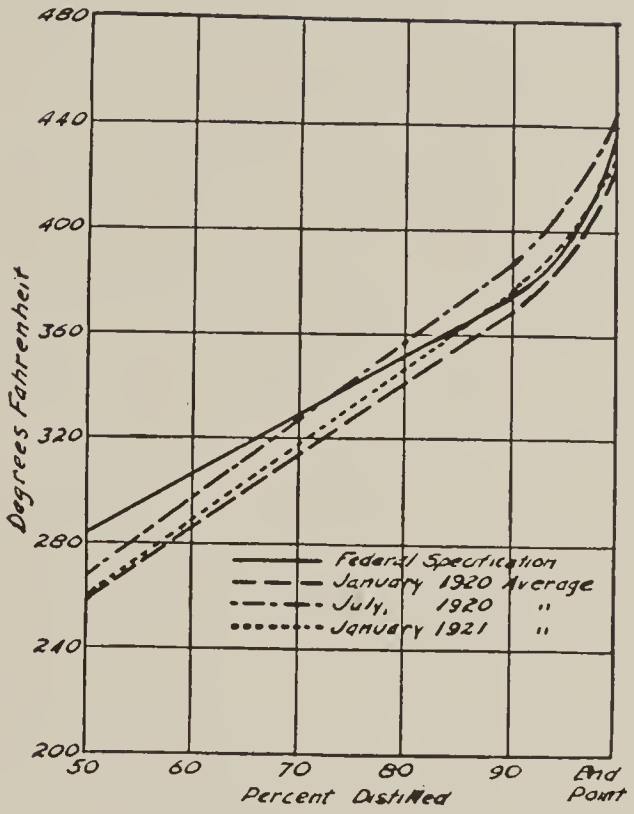

FIG. 2,

Dr. J. E. Pogue. See Automotive Industries, 40 (1919), p. 1319 et seq.)

Once the problem is clearly seen, our interest shifts to closely related questions. How has the supply of gasoline been increased so rapidly? Will it be possible to continue the increase by applying more intensively the methods already used, or other means which may be developed. The answer to these questions necessitates an analysis of each of the factors involved.

The present production of gasoline has been made possible by increasing production of crude oil, by marketing a gasoline of wider distillation range, by developing the natural gas gasoline industry, by applying cracking processes in the refineries, by blending coal tar distillates with gasoline, by importing petroleum from foreign countries, and by the fact that the crude oils distilled in recent years have contained a larger proportion of gasoline than those produced ten years ago. In addition to these, other means will be used in the future, the more important of which will be the production of alcohol from several raw materials, and the development of a shale-oil industry. Further than this, changes in the automotive industries will have their effect. We may expect important developments in the line of more efficient fuel utilization both because of mechanical changes in the engine and accessory devices, and because

it is now more generally recognized that investigation of the chemistry of the combustion process has been sadly neglected. A careful study of combustion may point the way to the satisfactory use of kerosene. Heavy oil engines are a distinct future possibility. Also, the steam car, that curiously neglected member of the automotive family, must surely receive further attention. All of these possible developments in the consuming industry are the equivalents of an increase in the output of motor fuel.

Production of Crude Petroleum in the United States

The domestic production of crude oil is the basis of our motor fuel supply. Table VI presents the figures of the U. S. Geological Survey for the marketed production of crude oil for each of the last thirteen years.

TABLE VI

Marketed Production of Crude Oil in the United States

Year	Barrels of 42 Gallons
1908	178,527,355
1909	183,170,874
1910	209,557,248
1911	220,449,391
1912	222,935,044
1913	248,446,230
1914	265,762,535
1915	281,104,104
1916	300,767,158
1917	335,315,601
1918	355,927,716
1919	377,719,000
1920	443,402,000[a]

We may well be proud of our achievements as they are shown in the above-mentioned table. But how long shall we be able to increase our petroleum production to meet the growing needs? This question has been in the minds of students of the situation for many years. Several estimates of our petroleum reserve have been made, presumably the most accurate of which is that of the U. S. Geological Survey as of January, 1919. (David White, "The unmined supply of petroleum in the United States," *Jour. Society of Automotive Engineers, 12* (1919), pp. 361–363.)

[a] Preliminary estimate of the U. S. Geological Survey.

Table VII presents the substance of this estimate.

TABLE VII

DATA ON PETROLEUM RESERVES

January 1919—Bbls. of 42 Gallons

Oil Field	Estimated Percentage of Exhaustion	Available Oil Left in Ground January, 1919	Average Gasoline Extraction Per Cent
Appalachian	69	550,000,000	28.0
Lima-Indiana	92	40,000,000	20.0
Illinois	63	175,000,000	22.0
Mid-Continent	36.5	1,725,000,000	24.0
North Texas	16.5	400,000,000	33.0
North Louisiana	47.7	100,000,000	28.0
Gulf Coast	29	750,000,000	1.5
Wyoming	9	400,000,000	40–50
California	33	2,250,000,000	12.0
Alaska, Colo., Mich., Montana, etc.	3	350,000,000	...
Total	...	6,740,000,000	...

The present reserve, calculated by correcting the above estimate by subtracting the production of petroleum in the period January 1, 1919, to April 1, 1921, is 5,800,000,000 barrels. At a rate of production equal to that of 1920, this would last only thirteen years. Obviously it would be impossible to extract the oil so rapidly. We may expect a production equal to or somewhat greater than that of 1920 for two or three years, and following that, a long period of decline. Doubtless none of us shall live to see the day when petroleum will not be mined in this country.

The youthful producing fields are those of Wyoming and North Texas. The Gulf Coast districts might also be included in this category. California and the Mid-Continent, the greatest fields of all, are at or near their period of maximum yield. North Louisiana, Illinois, and the Appalachian regions are declining. The Lima-Indiana field is nearly exhausted. Such, in brief, is the present status of our producing districts.

An interesting and important fact concerning the nature of our reserve supplies is shown in Table VII. Nearly one half of the petroleum remaining in the ground is the heavy oil of low gasoline content of the Gulf Coast and California fields. If we are to main-

tain our gasoline yield, we must devise methods of converting these heavy oils into gasoline. In 1920, the gasoline distilled from California oils comprised 15.3 per cent of the crude.

The data on petroleum reserves surely gives us something to think about seriously. Admittedly they are partly speculative, and for this reason they have been ridiculed by certain members of the oil fraternity. Actually they are the result of the conscientious effort of a group of scientific men to interpret a mass of accumulated facts as accurately as possible, and then to conservatively extrapolate the conclusions. Surely this procedure is more to be relied upon than the purely optimistic rejoinder of the oil producer to the effect that there will be more Cushings, Glenn Pools, Healdtons, or Midway-Sunsets. As has been said by Dr. George Otis Smith, "The motto inscribed on our silver coins should hardly be made a national policy in providing a future oil supply."

Importation of Petroleum from Foreign Countries

The United States, for many years, has produced two thirds of the world's petroleum. But in spite of this tremendous production we have drawn largely on foreign sources of supply. Importations have increased rapidly in the last three years. In 1920 our imports were twenty-five per cent of our domestic production, and were 36,000,000 barrels in excess of our combined exports of petroleum and all its products.

TABLE VIII

Imports and Exports of Crude Petroleum

Year	Imports	Exports	Difference
1913	17,809,000	4,620,000	13,189,000
1914	17,247,000	2,970,000	14,277,000
1915	18,140,000	3,765,000	14,375,000
1916	20,570,000	4,100,000	16,470,000
1917	30,162,000	4,098,000	26,064,000
1918	37,735,000	4,900,000	32,835,000
1919	57,000,000	5,924,000	51,076,000
1920	110,000,000	8,045,000	101,955,000

Since we are now dependent in large degree upon foreign supplies of crude oil, and since we are surely becoming more dependent,

it is important to inquire into the probable future availability of foreign oil. This subject is broadly treated in a paper by David White, Chief Geologist of the U. S. Geological Survey. (Annals of the American Academy of Political and Social Science, May, 1920.) This document, reprints of which can be obtained from the U. S. Geological Survey, should be read by everyone who is interested in the future industrial development of this country. How many of us realize that though we produce two thirds of the world's oil, we now use four fifths of it, and further that our reserves underground constitutes only 10–15 per cent of the total reserve of the world? Who controls the world resources? The following quotation from the *Financial News* (London) of February 24, 1920, is of interest in this connection:

"At the commencement of the war we believed that the effective British share of the oil resources of the world was about 2 per cent. Careful admiralty calculations, recently made, have shown that it is now about 56 per cent. This figure includes the Persian and Burmah resources, but takes no account of the vast South American fields commanded by the British controlled oil-fields. The exact amount of their contribution cannot, at the moment, be estimated with anything like precision. Probably a modest estimate might put it at another 19 per cent. If that be so, our present command of the world's oil resources runs to no less than 75 per cent of their entirety."—And we sometimes accuse our British cousins of being slow!

A similar view is given by the British economist, E. Mackay Edgar, in *Sperling's Journal* for September, 1919. He points out our profligate handling of our oil resource, mentions that the Royal Dutch and Shell groups alone control a fourth of the world's oil, and says "America is running through her stores of domestic oil and is obliged to look abroad for future reserves and, these reserves constituting a key position in international industry, are very largely in British hands or controlled by British capital. Before very long America will have to come to us for the petroleum she needs.

"We shall have to wait a few years yet before the full advantage of the situation begins to be realized. But that the harvest will eventually be a great one can be no matter of doubt.

"It will be within the limits of the commanding position that the future has in store for us to hold up the entire world to ransom in the distribution and the price of this vital essential."

Verily the British lion licks his chops!

The subject of petroleum in its international relationship is a large one and quite without the limits of this paper. But no one can have an entirely correct impression of our present position and probable future position without understanding the situation in some degree.

Table IX presents the estimate of Eugene Stebinger, prepared for the U. S. Geological Survey, and first published in David White's paper on the petroleum resources of the world. As admitted by its author, this estimate is at best a carefully considered scientific guess. Reliable data are available only for the oil regions of Roumania, Galicia, and the Baku and Grosny districts of Russia, and for these fields only can estimates of reserves be made comparable in their accuracy to the estimates of the resources of the United States.

TABLE IX

OIL RESOURCES OF THE WORLD

Country or Region	Relative Value	Millions of Barrels
United States and Alaska	1.00	7,000
Canada	.14	995
Mexico	.65	4,525
Northern S. America, incl. Peru	.82	5,730
Southern S. America, incl. Bolivia	.51	3,500
Algeria and Egypt	.13	925
Persia and Mesopotamia	.83	5,820
S. E. Russia, S. W. Siberia, and the region of the Caucasus	.83	5,830
Roumania, Galicia and W. Europe	.16	1,135
Northern Russia and Saghalien	.13	925
Japan and Formosa	.18	1,235
China	.20	1,375
India	.14	995
East Indies	.43	3,015
Total	6.15	43,055
Total Eastern Hemisphere	3.03	21,255
Total Western Hemisphere	3.12	21,800
Total North of the Equator	5.20	36,400
Total South of the Equator	.95	6,655

Dr. Stebinger's figures may be taken as an estimate of oil in sight. Dr. White believes that there are 20 billion barrels more in regions that have not been studied. The total world reserve may therefore be taken as approximately 60 billion barrels.

At present we are most interested in the possibilities of Mexican oil, since this producing region is being developed by American interests and since it is close at hand. It is difficult to gain a clear conception of the probable future production of Mexico. Shall we accept the opinions of geologists, or shall we believe the more optimistic reports of operators?

Dr. Ralph Arnold, eminent oil geologist, believes that the latter part of the year 1922 will see the end of the large proven fields of Mexico. (*Mag. of Wall Street,* April 2, 1921, pp. 782–3.) There have been twelve important Mexican pools, Ebano, Panuco, Topila, Das Bocas, Tepetate, Casiano, Los Naranjos, Chinampa, Zacamixtle, Cerro Azul, Potrero del Llano, and Alamo. Of these Das Bocas, Tepetate, Casiano, Chinampa and Potrero del Llano are extinct. Los Naranjos, Panuco and Alamo are rapidly going to salt water, and with the exception of Panuco, will soon be unimportant. Panuco and Ebano will produce a valuable emulsion for several years. This leaves Zacamixtle, a virgin pool, and Cerro Azul, a partly exhausted pool, to furnish the bulk of the supply. He estimates the oil remaining in the producing pools as 325,000,000 barrels. The present rate of production, 600,000 bbls. per day, will exhaust this oil before the end of 1922.

Arnold summarizes Mexican oil production and compares it to that of the United States as shown in Table X.

TABLE X

	U. S.	Mexico
Previous Producing Area	4,500 sq. mi.	25 sq. mi.
Number of Producing Wells	258,600	200
Production 1920	443,402,000 bbl's.	185,000,000 bbls.
Average Daily Production Per Well	4.9 bbls.	2,600 bbls.
Proven Oil Reserve (Arnold's Estimate)	5,000 to 6,000 million bbls.	300 to 400 million bbls.

Arnold indicates that there are other possible and probable oil-producing regions, but one cannot help but gain the impression from his article that the future of Mexico's oil has been pictured too rosily.

On the other hand E. L. Doheny, chief executive of the Mexican Petroleum Company, in the annual report of this company for 1920, gives a glowing account of Mexican conditions. Accord-

ing to Doheny, if the already proven, but slightly exploited, area in the Tampico-Tuxpam region should yield an amount of oil per acre equal to that taken from the practically exhausted pools, there will be produced from that limited part of the oil area of Mexico over 4,000,000,000 bbls. of petroleum. To quote Mr. Doheny, "The dire predictions of the ill-informed, even though educated, experts, indicate the predilection to pessimistic forebodings, due to their own successive disappointing experiences."

Possibly Dr. Arnold's prediction is too pessimistic, for we find that Dr. Stebinger has estimated the Mexican reserve as 4.5 billion barrels. Apparently no certain conclusions can be drawn. Surely under these conditions we should not allow ourselves to become dependent upon Mexico. The best that we can do when doctors disagree is to hope that the patient will "carry on."

If we cannot depend upon Mexico, what then? Most needed now is a firm foreign policy which shall insist upon an open door policy on the part of other nations. We have given the same opportunity to foreigners as to our citizens in the development of our oil resources. Yet today aliens are excluded from searching for oil in Burmah, India, Persia, Uganda, and the United Kingdom. In Algeria, Australia, Barbadoes, British East Africa, British Guiana, France, French West Africa, Guatemala, Japan, Formosa, Madagascar, New Guinea, and probably in South Africa we find that the policy of the government is to exclude foreigners from control of oil supplies.

"According to reports, mineral rights cannot be transferred to aliens in Australia, Barbadoes, British East Africa, British Guiana, the Dutch East Indies, France, French West Africa, Guatemala, India (probably), Madagascar, The United Kingdom, Japan (practically), Trinidad (in part) and, except that now held by other nationals, in Roumania and Slovachia. Ownership of the oil in the ground rests in the governments of Bolivia, Costa Rica, France, French West Africa, Slovachia, South Africa, Uganda, The United Kingdom and Venezuela, and in part in Argentina, Australia, British Guiana, Canada, Colombia, Ecuador, India, and Trinidad; and movements further to vest oil rights in the State are in progress in Colombia, Dominican Republic, Mexico, Roumania, and Russia." The quotations are from Dr. White's paper. Much of the information therein was summarized from a report on the subject of Inter-

national Policies affecting the World's Petroleum Industry, made by Dr. Manning to the Secretary of the Interior.

We must make every effort to obtain the same rights abroad as we offer to others at home, else we shall find ourselves in exactly the situation depicted by the British economist. Even as now, British corporations, backed by the government, are going abroad to secure every possible oil right, so it will be necessary for our corporations, possibly with government support, to more aggressively enter foreign fields other than Mexico.

Natural Gas Gasoline

The natural gas gasoline industry has been a notable contributor to the gasoline supply in recent years. Two processes are in general use. The compression process treats gases yielding over one gallon of condensate per 1,000 cubic feet of gas. The absorption method has been generally restricted to the treatment of the lean gas yielding less than one gallon of raw gasoline per 1,000 cubic feet. Commercial application of the compression process began in 1909 and of the absorption process in 1913.

The growth of the industry is shown in Table XI. The data are those of the U. S. Geological Survey. The figures for 1919 and 1920 are not as yet available.

TABLE XI

Natural Gas Gasoline

Year	No. of Plants	Gas Used Thousands of Cu. Ft.	Average Yield of Gasoline per 1000 Cu. Ft.	Natural Gas Treated Per Cent of Total Production of Natural Gas in U. S.	Natural Gas Gasoline Produced Gallons
1911..	176	2,475,...	3.00	..	7,425,839
1912..	250	4,687,...	2.60	..	12,081,179
1913..	341	9,889,...	2.43	1.7	24,060,817
1914..	386	16,894,...	2.43	2.8	42,652,632
1915..	414	24,064,...	2.57	3.8	65,364,665
1916..	596	208,705,...	0.496	27.6	103,492,689
1917..	886	429,287,...	0.508	54.0	217,884,104
1918..	1,004	449,108,...	0.63	62.0	282,535,550

Inspection of Table XI shows that the natural gas gasoline industry has grown fast. This has been possible since the industry depended upon the application of engineering processes to a large existent industry. At first the recovery of the gasoline was confined to treatment of the rich or "wet" gases from the casingheads of the wells. Since the advent of the absorption process the leaner gases have been handled. The result has been a tremendous increase in the total volume of gas processed, but a falling off in yield of gasoline recovered per 1,000 cu. ft. of gas treated. In 1918 99,897,000 M. cu. ft. of gas were treated by compression, yielding 2.2 gallons of gasoline per 1,000 cu. ft., and 349,211,000 M. cu. ft. of gas were treated by absorption methods, yielding 0.18 gallon of gasoline per 1,000 cu. ft. Absorption methods handled 78 per cent of the total gas, but produced only 21.2 per cent of the total product.

The natural gas gasoline industry contributed not quite 8 per cent of the gasoline produced in the United States in 1918.

What future developments may we expect in this industry? In my opinion its rapid growth is past. We shall see consolidation and the use of more efficient methods. But the industry has so widened in scope as to treat nearly the entire volume of gases that can be economically handled. The future course of the industry must run nearly parallel to that of the petroleum industry in general. So, though natural gas gasoline today constitutes approximately 10 per cent of our total gasoline supply, we should not expect to see any marked future increase in this proportion.

The Distillation Range of Gasoline

The increase in the distillation range of gasoline has been the most important means by which the supply of gasoline has been increased. The U. S. Bureau of Mines made a limited investigation of the quality of gasoline in 1915, more extensive surveys in 1917 and in 1919, and now makes semi-annual reports. These are summarized in U. S. Bureau of Mines Bulletin No. 191 "Quality of Gasoline Marketed in the United States," by H. H. Hill and E. W. Dean.

Ten years ago market gasoline was of 70° to 76° Baumé gravity, and distilled under 300° F. to 350° F. The distillation curve of the average gasoline of January, 1920, June, 1920, and of January,

1921, is shown in Fig. 2 along with the curve of government standard gasoline. (N. A. C. Smith, "Third Semi-annual Motor Gasoline Survey," Serial No. 2220 U. S. Bureau of Mines, February, 1921.) The Baumé degree of present market gasolines is between 54 and 60.

The change of distillation range from that of ten years ago to that of today has allowed an increase of 50 to 75 per cent in the amount of gasoline distilled from the oil. May we expect a future raising of the endpoint? Possibly it is significant that the Bureau of Mines Survey of January, 1921, showed that the average market distillate had not changed appreciably from that of January, 1920. The main question is as to whether a motor fuel of higher endpoint will be satisfactorily utilized. At least two difficulties must be overcome. In the first place the larger the proportion of higher boiling hydrocarbons in the gasoline, the more accurate must be the mixing of fuel vapor and air. This is evident if we write chemical equations to represent the complete combustion of hexane and dodecane.

$$C_6H_{12} + 9\tfrac{1}{2}O_2 \rightarrow 6CO_2 + 7H_2O,$$
$$C_{12}H_{26} + 18\tfrac{1}{2}O_2 \rightarrow 12CO_2 + 12H_2O.$$

To burn equal volumes of the vapors of the hydrocarbons nearly twice as much air must be used for the dodecane as for the hexane. Thus, the heavier the fuel, the more accurate must be the metering, This requirement should be met by engineering skill.

Another difficulty which is found in burning the heavier fuels is the development of a knock in the engine. I do not propose to discuss this subject at this time, but it is to be noted that this trouble is inherent in the nature of the fuel. It is probably caused by the rapid burning of the low molecular weight products of the dissociation and decomposition of the heavy hydrocarbons. The attack on this problem must be directed along fundamental chemical lines. It is difficult to say at this juncture just what the outcome may be. In any event, it would seem to be a more logical procedure to make two fuels, one a gasoline like that of today, and the other a kerosene, rather than to mix high-boiling and low-boiling hydrocarbons together in one heterogenous mixture. One should be used for the ordinary motor car, and the other for the truck and the tractor. This in fact is being done, and will doubtless lead to a more efficient utilization than if the fuels were mixed.

The relationship between the volatility of gasoline and the motor fuel problem may be summarized by saying that though broadening the boiling range has been means of greatly increasing the gasoline supply in the past, the approximate limit has now been reached, unless fundamental discoveries show how the detonative knock may be avoided.

The Distillation of Light Crude Oils

The increased average yield of gasoline obtained from the crude oil distilled in the refineries of the country has been due in some measure to the use of crudes containing larger perecntages of the more volatile hydrocarbons. These crude oils came into the market as a result of the development of the great Mid-Continent field, and more recently, of the Northern Texas, Northern Louisiana, and Wyoming fields.

The more extensive use of light crudes cannot be regarded as probable in the future, since, as I have already shown, one half of the petroleum reserve is in those regions that yield oil of low gasoline content.

The Development and Use of Cracking Processes

"Cracking" processes are those processes of thermal decomposition in which hydrocarbons of medium to high molecular weight are converted into a wide range of products, including lower molecular-weight hydrocarbons and higher molecular-weight hydrocarbons. The cracking process that produces a maximum yield of gasoline with a minimum formation of gaseous and tarry substances is the most successful.

Several hundred patents have been granted in this country and in foreign countries, covering methods or apparatus for the thermal decomposition of oils. These may be roughly classed into two groups:

1. Processes in which the oil in vapor form is thermally treated.
2. Processes in which the oil is treated in liquid form.

The first class of processes is sometimes referred to as vapor phase processes, and the second class, as liquid phase processes. The processes of Greenstreet, New Process Oil Co., Rittman, Alexander, General Petroleum Corporation, Parker, and Hall are ex-

amples of the vapor phase methods. The Burton process, and the pressure still processes of the Sinclair Refining Co. and of Cosden and Company are examples of the liqued phase method.

The Burton process in the hands of the several Standard Oil Companies has been developed more extensively than all the other processes put together. No exact statistics are available that show the quantity of gasoline produced today by cracking methods. In 1918 Dr. Burton estimated that 10 per cent of the marketed gasoline was so made. A reasonable guess is that 15 per cent and probably more of the gasoline sold today is produced by these special methods.

I am firmly convinced cracking processes will be developed that will largely overcome the present objections to these processes. Technically the methods of thermal decomposition are in their infancy. This is attributable first to the fact that the necessity for cracking methods has not long existed. It is further due to the fact that only recently have the large refiners engaged competent chemical engineers. An engineer without specialized chemical training is incompetent to develop methods for the thermal treatment of oils. And a chemist with limited, or no, engineering experience is little better off. Most important of all, the chemical engineer who is really competent to undertake development work, is hampered by the lack of fundamental knowledge of hydrocarbon reactions, and the effect on the course of these reactions of changes in the ordinarily considered variables, time, temperature, and pressure. When other variables, such as the presence of catalysts, differences in shape and design of apparatus, and effect of surface forces are also introduced, the problem assumes real complexity. It is not surprising that no one rational and satisfactory solution has been discovered so far.

The most notable single fact in the situation today is that the developed processes handle only the middle distillates. Gas oil and the slightly heavier distillates are treated successfully. The real problem is the development of methods which will satisfactorily convert the heavy fuel oils and residuums, in part, into gasoline. For, where there is 10 or 15 per cent of middle distillates in average crude oil, there is 45 to 50 per cent of the residuum or fuel oil. A small part, only, of the heavier portion is needed for the manufacture of lubricating oils. The use of oil for fuel, except for naval purposes, and to a limited extent in localities where coal is not available, is a flagrant waste of a valuable resource. Today the demand

for gasoline is the factor that controls the production of crude petroleum. If two gallons of gasoline are obtained where but one was obtained before, the production of crude oil can be cut to a point consistent with the status of the resource.

So, if I were to select one factor more important than all others in the present motor fuel situation, I should say that it is the necessity of developing methods which will economically produce gasoline from the heavy 45 to 50 per cent of our crude oil. Pressure still methods, for practical reasons, are not suitable. A carbon deposit is quickly formed on the heating surface, which insulates the metal. The plate or tube is overheated and failure may occur.

I am convinced, however, that there is no need for the use of pressure, and that processes will be developed which will solve the difficulties encountered in the handling of heavy oils. It is of the greatest importance that this be done, for whatever may be our future motor fuels, or our future automotive engine, there will be a transitional period in which it will be necessary to obtain the largest yield of gasoline from our own and from foreign crude oils. The most logical and the simplest solution for the motor fuel problem of this transitional period will be simplification and more extensive development of cracking processes.

Further than this, future profitable utilization of oil from shale will depend upon the application of cracking processes that will produce gasoline from the heavy hydrocarbons of this oil.

Also it should be noted that the *use* of a suitable cracking process capable of handling heavy oils allows of great flexibility in the operation of a refinery.

No mention of cracking processes can be made without calling to mind a further point which is often raised as one of the chief objections to these methods, particularly to the vapor phase processes. The difficulty to which I refer is the formation of olefin hydrocarbons and the difficulty of marketing gasolines containing large proportions of these unsaturated substances. The issue is side-stepped by refiners today, as they blend the olefinic distillates with saturated distillates and so avoid trouble.

The olefinic gasolines are objectionable, not because of any difficulty of burning the fuel once it is within the cylinders of the engine, but because the olefins, when vaporized, mixed with air, and warmed somewhat, oxidize and polymerize to form gummy

and tarry substances which obstruct passages in the carbureter and manifold pipes, and which coat the valves. So far as I am aware, no published information is available as to what the upper limit of olefin content may be for a satisfactory motor fuel. In fact, there is at present no method which gives an even approximately accurate determination of the amount of unsaturated hydrocarbons in gasoline. The sulphuric-acid method as applied by various analysts gives widely varying results. The variations are dependent upon the strength of the acid, the time and extent of the contact of the acid and oil, and on the nature of the olefins in the oil. Determinations of "olefins," as reported in the technical literature today, are valueless and even misleading. They are never too low, but often indicate a low per cent of olefins when actually the amount present may have been from 1½ to 3 times that indicated. In the case of the heavier distillates, the olefins may constitute the larger part of the oil, and yet the sulphuric-acid method will indicate but a small percentage.

The formation of olefins in the vapor phase processes is less, the lower the temperature of cracking. A long time of exposure at a low temperature is one of the secrets of the successful working of these processes. Another important question is the use of small tubes. The conditions for heat transfer are poorest in a short large tube and best in a long tube of small diameter. Furthermore the introduction of low molecular weight molecules to act as heat transferrers is advisable. The fewer the contacts between the tube wall and hydrocarbon molecules, the better; for these contacts result in a disruptive decomposition. Hence it is better to introduce inert molecules of low molecular weight, and therefore of rapid molecular movement, which will contact with the metal walls, thus having their kinetic molecular energy increased. They will in turn dive out again into the body of the gas stream to give up this energy by molecular collision. If I add to the factors I have mentioned, the further requirement that all conditions, *i.e.*, feed of the raw materials to the cracking tubes, temperature, and pressure (if pressure is used), must be most carefully controlled, I have stated the more important requirements for success in vapor phase cracking.

Vapor-phase cracking will occupy a more important position in the future than it does today; for the processing of heavy oils

always produces distillates that are suitable raw material for vapor-phase cracking, and with the more extended development of the former methods we may expect to see a further development of the latter.

Aromatic Hydrocarbon Distillates

The use of the lighter distillates from coal tar, or of these same hydrocarbons, benzene, toluene, and the xylenes, as they are scrubbed from coke oven or coal gases, has proved entirely satisfactory. They may be used alone, but are preferably mixed with gasoline. Also they serve as useful blending agents in case it is desired to make mixed fuels containing gasoline and alcohol.

To what extent will these substances fill in the gap between future motor fuel supply and demand? A brief examination of statistics shows that we must not expect too much from them. In Table XII is shown the number of gallons of the volatile aromatic distillates, i.e., benzene, toluene, xylenes, and solvent naphthas ("Census of Dyes and Coal Tar Chemicals, 1919," Tariff Information Series — No. 11.)

TABLE XII

Production of Aromatic Hydrocarbon Distillates (in Gallons)

	1917	1918
By-products from the manufacture of coke	53,385,000	145,399,000
By-products of coal-gas plants	7,533,000	10,408,000
Products of coal-tar distilleries	6,088,000	5,575,000
Other	4,805,000	4,107,000
	71,811,000	165,489,000

The total production of aromatic distillates in 1918 equalled only 4.7 per cent of the total gasoline production of that year, and only 3.4 per cent of the gasoline production of 1920. These percentages are so small as to make it seem scarcely worth while to consider these distillates as motor fuels, particularly since a large demand for these products comes from other industries in which they are used as raw materials or as solvents. But in spite of this seeming unimportance it will be found that several corporations will derive substantial returns from the sale of these products as fuels. So great is the total volume of motor fuels sold annually in this country that even 1 per cent of the total business is to be counted in millions of dollars.

The solution of the motor fuel problem will be not be found in the use of aromatic distillates. This is obvious from the foregoing table. The production of these products is largely dependent upon the scope of the by-product coking industry, and this in turn upon the steel industry. A healthy growth is to be expected, but nothing phenomenal or startling. The percentage of coal coked in by-product ovens and in gas plants will also increase. In 1918 the coal so processed was 46 per cent of the total. Today it is probably over one half. Even with the continuance of present tendencies it seems hardly probable that over 5 per cent of the total motor fuel supply of the near future will consist of aromatic distillates.

The Possibility of a Shale Oil Industry

High prices for petroleum, along with a growing recognition of the limitations of our oil reserve, have served to awaken interest in the commercial development of our great oil shale resources. The U. S. Geological Survey has studied these deposits, particularly the rich shales of the Uinta Basin. Dean Winchester estimates (U. S. Geological Survey Bulletin No. 691–B) that the shale in the Utah portion of the Uinta Basin alone would yield 42,800,000,000 barrels of crude shale oil. He estimates further that the shales of Colorado would yield 20,000,000,000 barrels of the crude oil. (U. S. Geol. Survey, Bulletin No. 641–F.) Dr. Victor Alderman believes these latter shales are capable of producing 58,080,000,000 barrels of oil. ("The Oil Shale Industry," by V. C. Alderson, p. 31.) These are figures beyond the limits of the imagination, and we may be well satisfied to pass off small variations in the estimate with a modification of the old placative saying—"Anyway, what is a matter of a few billion barrels between friends."

But to have, and to utilize, are two different matters. No large scale production of shale oil is now under way, though much experimentation in the laboratory and in full sized retorts has been caried out; and the Patent Office has taken up a new form of indoor sport in the shape of shale oil process applications.

Technical, economic, and social problems must be solved before shale oil can become an actuality on a large scale. Technically the production of shale oil involves the cheap mining and handling of enormous quantities of shale, the retorting of the shale in such a way as to produce a maximum of oil of good quality, and finally

the refining of the oil into gasoline, kerosene, distillates, lubricating oils, and fuel oil. The retorting operation is the first and most important step. This should be carried out at as low a temperature as possible to avoid secondary decomposition of the hydrocarbons of the oil, and the consequent formation of olefins. The shale should be treated in relatively thin layers, else the conductivity of heat will be so poor as to necessitate an excessive retort-wall temperature. The hydrocarbons first formed from the shale should be removed from the retort as rapidly as possible, and to this end the circulation of an inert gas through the retort should be advantageous.

The successful utilization of shale oils in the production of motor fuels will necessitate the use of cracking processes. The problem is much the same as that of working up the heavy fuel oils and residuums. This I have already discussed.

Economically the development of shale oil depends upon attracting large amounts of capital. The investment necessary for the production of given volume of finished products will be larger than that necessary for the production of these products from petroleum. The interests to whom shale oils should appear most attractive are the western railroad companies that use oil for fuel.

From a combined economic and social standpoint, the development of the shale oil industry would necessitate the building of cities and the evolution of new communities in what are now barren and arid regions of the West. As Mr. Requa has pointed out, the mining of shale oil on a scale sufficiently large to produce a quantity of oil equal to the present output of petroleum would require the services of a labor army nearly equal to that now engaged in the mining of coal. This gives a truer picture of the size of the task than perhaps any other comparison, and shows at once that we cannot expect shale oil quickly to take the place of a failing supply of petroleum.

Alcohol as a Motor Fuel of the Future

The value of ethyl alcohol as a motor fuel when used in admixture with gasoline or aromatic hydrocarbon distillates has been amply demonstrated. Alcohol and gasoline are not completely miscible, but the addition of blending agents such as benzene or, preferably, small amounts of ether, renders them miscible. The mixed

motor fuels containing 30 to 40 per cent of alcohol, an equal or somewhat larger per cent of gasoline, along with smaller percentages of benzene and ether, can be vaporized by the ordinary carbureter and used in present type engines as satisfactorily, and probably more satisfactorily, than gasoline. The use of pure alcohol necessitates special engines with a high compression ratio. Without widespread facilities for the distribution of alcohol the owner of a car using alcohol as fuel would always be inconvenienced. It is fortunate therefore that alcohol fuel mixtures have proved practical.

How is a large future supply of alcohol to be provided? This is the question that makes students of the motor fuel problem skeptical of the future importance of alcohol as a motor fuel.

Over four fifths of the present output of industrial alcohol is made from cane molasses. The world's production of sugar in late years has approximated 40,000,000,000 pounds. Of this 61.5 per cent is cane sugar. Obviously the alcohol manufacturers of this country can never control all of the world's by-product molasses. One third of the world's total cane sugar is consumed in this country, and it is reasonable to suppose that we should be able to control one third of the cane molasses, or approximately 200,000,000 gallons per year. From this quantity of molasses 85,000,000 gallons of 95 per cent alcohol can be made. This is only 1.75 per cent of the present motor fuel production in this country. It is clear, therefore, that large future supplies of alcohol cannot be produced from the present main raw material, molasses.

Other materials used today are beet molasses, grains, potatoes and sugar beets. The following tabulation shows the raw material cost for one gallon of 95 per cent alcohol made from these materials. For comparison cane molasses is also included.

TABLE XIII

Raw Material	Assumed Cost per Unit f.o.b. Plant	Cost of Raw Material for 1 Gallon of 95 per cent. Alcohol
Cane molasses	5 cents per gallon	11.75 cents
Beet molasses	5 cents per gallon	12.0 cents
Corn	43 cents per bushel	15.7 cents
Potatoes	25 cents per bushel	31.0 cents
Sugar beets	$5.50 per ton	25.0 cents

The raw material cost of alcohol is seen to be prohibitive except in the case of manufacture from corn. But any extended use of corn would raise the cost of this grain to such a point as to make it also too expensive.

The possibility of manufacturing larger quantities of alcohol seems to me to be limited to the making of alcohol from acetylene, from ethylene or from wood.

The economical production of alcohol from acetylene necessitates cheap electrical power. With power at $16 per horsepower year, or with the cost of calcium carbide at $30.00 per ton, the raw material cost for alcohol would be approximately 15 cents per gallon of 95 per cent alcohol. The availability of large quantities of cheap power in this country definitely restricts the manufacture of alcohol from acetylene to a small production.

Ethylene I regard as a more probable limited source of alcohol. The cracking of oils, especially vapor-phase cracking, results in the formation of ethylene, propylene, methane, ethane, hydrogen, and smaller amounts of other hydrocarbon gases. The percentage of ethylene and propylene in these gases varies from 10 to 50 per cent, and depends mainly upon the type of oil used and the temperature of operation. The cracking of distillates from paraffin-base crudes yields gas containing a much larger proportion of the olefins than does the cracking of cyclic-base distillates. Assuming that 10 per cent of the total production of petroleum is cracked with formation of 50 cubic feet of by-product gas per barrel of oil processed, and that the gas contain 20 per cent olefins, the possible annual production of alcohols would be 20 to 25 million gallons.

The manufacture of ethyl alcohol from wood is the most promising of the future possibilities. The hydrolysis of the wood substance by means of dilute acids has been carefully studied by Tomlinson, Kressman, and others. The laboratory yield of alcohol is as high as 35 to 40 gallons per ton of dry wood. Plant yields have been only half as large. Kressman estimates the cost per gallon of alcohol at 20 cents under ordinary conditions. Tomlinson has suggested that present wood wastes may be utilized by producing molasses at the saw-mill, and then shipping this to alcohol plants located near the centers of consumption.

The possibilities of finding better methods of hydrolyzing wood to fermentable sugar have not been exhausted. Nor is utilization

of waste wood the only reasonable basis for established alcohol production with wood as raw material. Reforestation of unused areas with rapidly growing species of trees is surely a possibility. Extensive reforestation would require a large outlay of capital, and might be possible only if the owners of the properties were freed from the taxes normally imposed upon timber land. The integration of an alcohol industry based on these lines is apparently no more sizable a task than the development of a shale oil industry.

It appears then, that the production of alcohol may be increased moderately by the extension of activities along tried lines, and also by the development of processes making alcohol from ethylene and acetylene. But large quantities of alcohol can only be produced by the utilization of wood as the raw material.

Engine Development

Another solution, or part solution, of the motor fuel problem lies in the development of engines which will successfully utilize the heavier oils as fuel. Will the Diesel engine or the semi-Diesel engine be adopted to use on tractors, trucks, and possibly even on pleasure cars? This question is being studied, but as yet no definite trend is evident. May not the chemist do much to aid in the study of the problem? One of the chief obstacles to the use of heavy oil engines is their weight, necessitated by the excessive pressures used within the cylinders. If the rate of combustion of the fuel could be increased by the use of catalysts, and the pressure necessary correspondingly decreased, a much lighter engine could be built. A limited amount of investigation along this line has been carried out.

A further possibility lies in the building of explosion engines that will burn kerosene without serious difficulty from knocking. The use of catalysts may also have a bearing on this problem. The difficulty in the burning of kerosene is apparently related to the fact that two processes, combustion, and thermal decomposition of the hydrocarbons, are taking place simultaneously in the cylinder. If the thermal decomposition could be inhibited, or the combustion brought about at lower temperatures, the difficulty would be avoided. Experimentation with catalysts is clearly suggested.

Finally we may inquire whether the steam-driven automobile has not been neglected. Would not the objections to the steam

car be overcome by the application of even a small part of the energy and ingenuity that has been applied to the development of the present gasoline car. The steam car is far more flexible in operation than the gas car. No changing of gears is required. It is reasonable to believe that burners can be designed that will permit burning of heavy distillates. And compared to difficulties that have been successfully overcome in the building of gasoline cars, the problem of developing a suitable and lasting boiler for the steam car is not formidable. Is it not possible that our automotive engineers have been travelling in the rut of unintentional prejudice, formed as a result of their schooling and experience in the years of development of the gasoline engine driven car?

Whatever may be the outcome in the field of engine design and development we may expect some improvement in the direction of economy and utilization of heavier fuels. In this way the motor fuel problem may become somewhat less formidable than it now appears.

Summary

The motor fuel problem is one of the great problems of the present day. The solution demands readjustment and development in the petroleum and related industries, and in the automotive industries. Many of the problems are distinctly within the province of the chemical engineer.

The consumption of gasoline is now nearly five billion gallons annually, and may be expected to increase to seven billion gallons. Production of gasoline has kept pace with demand as a result of the increased production of crude oil, marketing of a gasoline of wider distillation range, the development of the natural gas gasoline industry, the application of cracking processes, the blending of coal-tar distillates with gasoline, the importation of petroleum from foreign countries, and of the fact that petroleums distilled in recent years have contained a larger proportion of gasoline than those of ten years ago.

The United States produces two thirds of the world's crude oil, but uses four fifths of it. Our reserve supply below ground is 5,800,000,000 barrels, which, at a rate of production equal to that of 1920, would last only thirteen years. We are now dependent upon foreign crude oils, and are importing more crude oil than our combined exports of petroleum and its products.

Great Britain now commands three fourths of the oil reserves of the world. We must insist upon an open door policy on the part of other nations with regard to development of oil resources by our nationals. Our petroleum reserves are only 9 per cent of those of the entire world.

We cannot expect a further rapid expansion of the natural gas gasoline industry, nor can the distillation range of gasoline be further materially increased. Chemical research must point the way toward success in utilization of the heavier distillates as motor fuels.

The problem of the transition from present sources of motor fuel to future sources will be solved by the development of cracking processes. The most important single technical problem is the cracking of the heavier 40 to 50 per cent of petroleum, the fuel oil or residuum. Processes now in use handle the middle distillates only.

The use of aromatic distillates as fuel will never be of great consequence.

Development of an alcohol industry based on wood as a raw material, and of a shale oil industry, may be anticipated. Both are tremendous undertakings, and should not be expected to develop rapidly. A noteworthy field of investigation is the study of the combustion process from a chemical standpoint, and important changes in the design of engines and accessory appliances may result. The much neglected steam-car may receive the attention to which its advantages truly entitle it.

The motor fuel problem is one needing serious thought and constructive work on the part of individuals, corporations, and government.

CHEMICAL ENGINEERING DEPARTMENT,
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MORE MILES PER GALLON

A Discussion on Carburetion as Affecting Motor Efficiency, Brake Horsepower and Work—Spark Timing and Brake Load—Relation Between Torque and Engine Speed—Possibilities of More Efficient Utilization of Motor Fuels

By O. C. Berry

Read at the Detroit Meeting, June 23, 1921

So much has recently been said about the possibility of fuel shortage that most of us probably have the facts clearly in mind and have formed an opinion as to what we expect to see happen. Our viewpoints will differ, however, so that there will be nearly as many opinions as there are people present, but I feel sure we can all agree that the threatened fuel shortage will not take place this year nor next and that we can expect to experience at least the first effects of a real shortage within the next ten or fifteen years.

The past growth of the automobile industry would have been impossible had it not been for an abundant supply of cheap fuel. So rapid has been this growth that in a single generation we are consuming annually approximately four billion gallons of gasoline in the United States, and our Bureau of Petroleum Technology estimates that our known petroleum reserves are 40 per cent exhausted. We have not yet reached the point where we can expect a sharp increase in prices, however, as production is still able to keep pace with demand, and the price of any commodity tends to follow one of two standards:

When the raw material is plentiful and generally available, the price of the finished product will tend to be the cost of production plus a reasonable profit.

When the raw material is hopelessly inadequate, the price of the finished product will tend to rise until it represents all that the user is willing to pay rather than be utterly deprived of the product.

I feel safe in making the prediction that the production of gasoline in the United States will not be able to keep ahead of the demands of our growing automotive industry for as many as fifteen more years, so that the shift toward the utility value of gasoline as a measure of its price will be taking place in less than that time. We will soon see the time when any man who rides in an uneconomical car is not only paying too much for his ride and forcing up the price of fuel, but is also forcing some neighbor to stay at home for lack of the fuel he has wasted. In France at the present time gasoline is selling at $1.90 per American gallon. What can we rich Americans expect to pay when our supply runs short?

Postponing the Inevitable Fuel Shortage

From present indications it would seem that a fuel shortage is inevitable, but there are many things we can do to postpone it and to lessen its ill effects when we are forced to face it.

We can hunt for new petroleum deposits, and thus increase our available supply of raw material.

We can learn how to cut down the present wastes in mining and storing petroleum.

We can learn how to produce more gasoline per barrel of petroleum used at the refineries.

We can learn how to make substitute fuels on a large scale and at a low price.

We can learn how to get more out of each gallon of fuel we use.

We must depend upon the mining engineer and the " wildcatter " to locate more oil deposits and upon the petroleum technologist and chemist to prevent wasting the oil during mining and storing operations. To the chemist we owe what we know about the methods of making our most effective substitutes for gasoline — benzene and alcohol — and to him we must look for our future help along these lines. The discovery of an economical method of producing shale oil or an efficient method of making alcohol from farm wastes would prove a great help. The latter would be almost a complete solution for our problem. We commend these problems to this great body of scientists.

It is my purpose not only to point out what the chemist can do to make it possible for the world to ride in automobiles, but to stimulate him to action by pointing out what the automotive engi-

neer has done and is doing. You will be interested to know that it is possible to nearly double the miles per gallon of the American automobile. In a recent economy test in France a Voisin limousine weighing 5,300 lbs. went 28.3 miles per American gallon. A Citroen car weighing 2,500 lbs. went 53 miles per gallon and a 1,200-lb. Peugeau went 76.9 miles.

Contrast these figures with the performance of the average American car and you will see that our room for improvement is indeed great. Probably there is no one feature of our cars that has received less of the careful attention of our engineers in the past than has their capacity for economical running. There are no features incorporated in foreign cars for fuel conomy that we do not know about and understand and I do not concede for a moment that the foreign engineer is one whit more resourceful or well-informed than the American. It is therefore up to us to look the situation squarely in the face, and recognizing the importance of fuel economy, to make a careful study of all of the factors influencing miles per gallon and to see to it that every possible improvement is incorporated in the design of our future models. With these facts in mind, I have set about making such a study and am pleased to be able to present some of the information I have assembled.

Carburetion

One of the outstanding reasons for the poor mileage of the average American car is poor carburetion, or more accurately poor carburetor adjustment. In order to make this clear it will be necessary to show the effect of the richness of the fuel mixture on the power and economy of an engine. In studying this point, use was made of a Willys-Knight engine mounted on an electric dynamometer. The results of these tests are shown by the curves in Fig. 1. In these curves the pounds of gasoline per pound of dry air in the fuel mixture is plotted horizontally and brake horsepower and per cent thermal efficiency vertically. In carrying out these tests the throttle was arranged so that it could be securely fastened, and all of the tests were run at a constant engine speed. The gasoline was weighed to the one-hundreth part of an ounce, the air metered to the tenth part of a cubic foot, and the brake-load, speed, temperatures, etc., were carefully measured. Under these conditions and with the carburetor adjusted to give a rich and powerful mixture,

the first test was run. The power, efficiency and mixture ratio were then computed and a point established on both the power and efficiency curves. The gasoline adjustment was then made slightly leaner, the brake-load adjusted to produce the correct speed and a second test was run. This procedure was repeated until the mixture became too lean to allow proper engine performance. More gasoline was then introduced each time until the mixture was entirely too rich. The mixture was thus made alternately richer and leaner

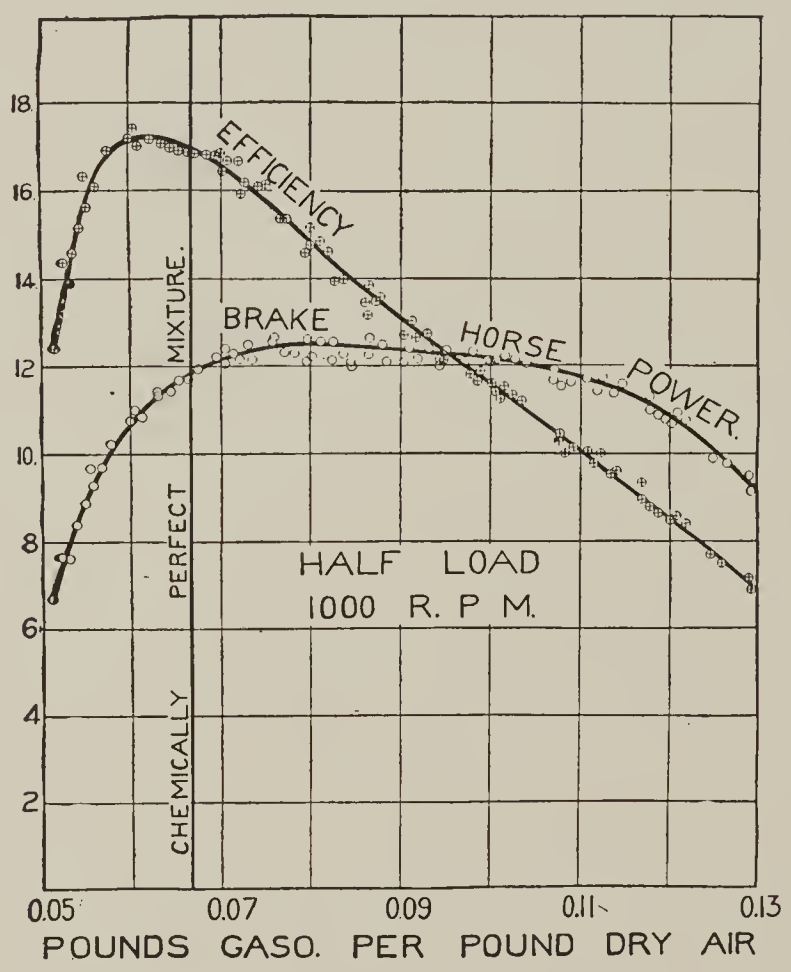

FIG. 1. Efficiency and Brake Horsepower Curves

until a sufficient number of points had been located on each curve to indicate quite clearly the effect of the richness of the fuel to air mixture on both the power and the efficiency of the engine.

It will be noted that there is a wide range of mixtures through which the richness has but little effect on the power of the engine. The lean and the rich mixture give equally good power, and both result in what seems to be perfect engine performance. This accounts for the fact that the comparatively crude caburetors of earlier day gave quite satisfactory performance.

The range of mixtures giving the highest efficiency is very nar-

row, and corresponds to about the leanest mixture with which the engine will run without missing. As more gasoline is added the efficiency drops off very rapidly, so that the richest mixture producing full power will result in only about half maximum efficiency. This explains why it is that of two cars of the same make and both performing nicely, one may go nearly twice as many miles per gallon as the other.

Why Over-Rich Mixtures Are Used

There are several reasons why so nearly all of our carburetors are adjusted so as to give too rich a mixture when the engine is hot.

Gasoline flows much more slowly when cold than when warm, so that an opening large enough to deliver the required charge to a cold engine will inevitably deliver too much when the engine is warmed up.

Cold air is denser than warm air, so that the weight of air delivered through the air opening in a carburetor will be greater when the air is cold than when it is warm, thus causing the mixture to become richer as the temperature of the engine increases.

For these reasons the mixture furnished by a carburetor with a fixed adjustment will become richer as the temperature rises. To make matters worse, not nearly all of the gasoline in a cold mixture is vaporized so that it can be burned. This makes it necessary to supply a considerable excess of fuel in a cold mixture to get the engine to run at all.

The American public has been taught to demand a car that will start easily in any kind of weather and continue to run without requiring any attention or adjusting. They have been supplied with a large variety of non-adjustable, or what has aptly been termed "foolproof" carburetors. These carburetors will deliver a mixture rich enough to start well in cold weather, and due to the great range of the explodable mixtures of gasoline and air, will keep the engine running with full power and seemingly perfectly in summer or in winter. The only fault to be found is that when the engine is hot the mixture is often 50 to 75 per cent richer than necessary and the miles per gallon are correspondingly low. A non-adjustable carburetor cannot be made so that it will make starting easy and also give high efficiency in driving.

Dash Adjustments

A carburetor adjusted for maximum economy on a hot engine will be too lean to start when cold. There are two ways in common use for meeting this situation.

A choke may be supplied that can close off the main supply of air to the carburetor, thus enriching the mixture.

A means of adjusting the carburetor may be connected up to the dash or the steering post of the car.

The action of the choke is very severe. It causes raw gasoline to be sucked into the engine in large quantities. Its action becomes increasingly severe as the engine speeds up, so that if the mixture is rich enough to start the engine it will be much too rich after considerable speed has been obtained.

The dash adjustment may be made very satisfactory in its action if correctly used, and quite convenient as well. Its use is easily understood, as the idea is to get it set as lean as possible, and it is very easy to tell when it is too lean, as the engine will lose power and fire back through the carburetor. A proper dash adjustment set right for one speed and load will be correct at all speeds and loads at the same temperature, and will need to be changed only as the temperature changes. The mixture should be just right for a hot engine with the dash adjustment set at its leanest position.

Discussion of Curves

The curves in Fig. 1 show that a richer mixture is required for maximum power than for maximum efficiency. It is therefore obvious that a carburetor adjusted for maximum "miles per gallon" will be too lean to give the full power of the engine. This difficulty can be got around in this way: When driving on a level road at any speed that the law allows the engine is never called upon to deliver nearly its full power. Under these conditions the most important consideration is economy. When a steep hill is to be climbed, acceleration is desired or a neighbor wants to race, full power is the important thing. The constant speed driving is done with the throttle pretty well closed and the power work with the throttle wide open. It is possible to design a carburetor that will furnish the engine with the most economical mixture at all ordinary speeds on a hard, level road, and with the most powerful mixture when the throttle is wide open.

The fuel is almost never entirely vaporized in the intake manifold of the engine. A considerable portion flows along the manifold walls as a liquid, and lags behind the air that passed through the carburetor with it. When the engine is idling this layer of liquid is very thin, but under full load it usually forms quite a large stream. When the engine is put under load quickly, the air rushes ahead, leaving at least a portion of liquid on the manifold walls. If the mixture is lean enough to be efficient under steady running conditions, this temporary impoverishment will often be sufficient to stall the engine. It is therefore necessary to incorporate into the design of the carburetor some special means of temporarily enriching the mixture during acceleration. There are many types of construction in use, some of which are very satisfactory. It is therefore possible to get perfect acceleration even when using a mixture lean enough for maximum efficiency. The more perfect the manifold design the easier this becomes, and with the very best manifolds very little special provision is necessary for acceleration.

The Ideal Carburetor

In my estimation the highest type of carburetor yet developed for our American gasoline will meet the following requirements:

It will furnish the engine with the most efficient mixture when the car is driven at a constant speed on a hard, level road.

It will furnish the engine with the most powerful mixture when the throttle is wide open.

It will make perfect acceleration possible, even when adjusted for maximum economy.

It will have a dash adjustment that will make starting and warming up an easy matter, even in the coldest weather.

There are carburetors on the market meeting all of these requirements. They make much better "miles per gallon" possible, as well as being more satisfactory to handle than the cruder "fool-proof" varieties.

The Timing of the Spark

The second factor influencing the economy of the automobile is the timing of the spark. If the spark passes too early it will lessen the power of the engine and tend to produce what is called a "spark" knock. If it passes too late it will also reduce the power

of the engine. The proper timing of the spark in any given engine will vary with two things — the load the engine is carrying and the speed at which it is running. The latter fact is pretty generally understood, and nearly everybody knows that the faster an engine runs the earlier the spark must pass to give best results. The former fact has received comparatively little attention and will therefore be enlarged upon at this time.

In making a study of this point an engine was mounted on an electric dynamometer in such a way that the exact time of the passing of the spark could be read, as well as the speed of the engine and the brake-load carried. The engine was run at a series of different spark settings at each of a series of different throttle openings. The results of these tests are shown in Fig. 2. In these

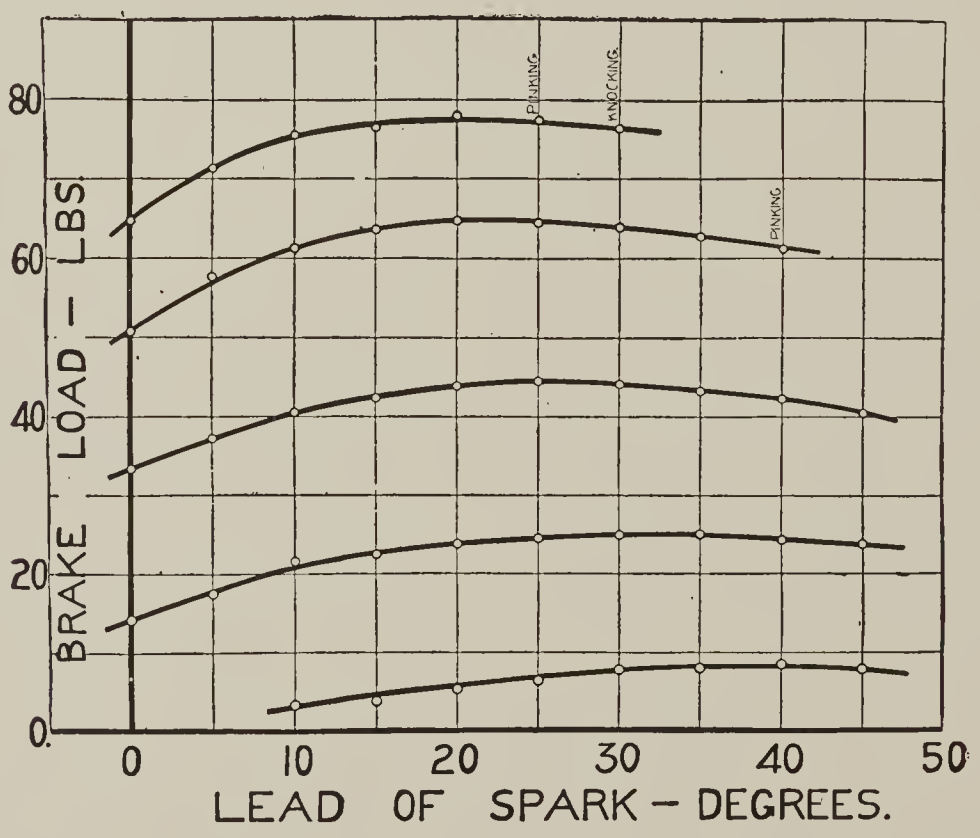

FIG. 2. Degrees Advance of Spark over Flywheel and Brake-load

curves the lead of the spark in degrees on the flywheel is plotted horizontally and the brake-load carried is plotted vertically. All of the tests were made at 1,000 r.p.m. Each curve was made at a constant throttle opening, the brake-load being changed along with the spark timing to keep the speed constant.

It will be noted that a lead of 20 degrees is required for maximum power at full throttle, and a lead of 25 degrees will result in a knock. As the throttle is gradually closed the lead required

for highest power is gradually increased until with the lightest load carried, a lead of 40 degrees is required. At this throttle opening the engine will carry only 60 per cent as much load with a 20-degree spark lead as it does with a 40. It is so disagreeable to have an engine knocking during acceleration and hill climbing that the spark is almost never advanced beyond the point where knocking occurs at full load. Since the engines in our American cars run at such a low per cent of their power capacity, the spark is timed much later than it should be for greatest economy, resulting in a considerable loss in miles per gallon.

The vacuum in the intake manifold of an engine varies in almost inverse ratio with the brake-load carried. It therefore follows that the lead required by the spark at a light load beyond that required at full load will vary directly with the intake manifold vacuum. This fact has been made use of in producing an automatic device for changing the time of the spark to correspond to the load carried. This device, when properly installed together with a standard controller compensating for speed, provides a completely automatic means of timing the spark that is very accurate. This device is not on the market at the present time, but I have personally conducted a series of tests showing its merit, and feel confident that it will be perfected and presented to the public in the near future. When properly installed it should add considerably to the economy obtained by the average driver.

The Load on the Engine

Another opportunity to improve the economy of our automobiles has to do with the large reserve power in the engines. A good American car can climb a steep hill in high gear, and accelerate very rapidly.

This delightful "activity" necessarily means that under ordinary driving conditions on a hard, level road the engine is called upon to exert a very small per cent of its full torque capacity. In order to get accurate information on this point, a car was chosen of a make known to be carefully designed, well built and a good average accelerating ability, about 3.2 ft. per sec. per sec., and tests were made showing the torque capacity of the engine and the power required to propel the car at varying speeds. The results of these tests may be taken as representing the average performance of good American cars.

The method of conducting the tests was to insert between the carburetor and intake manifold a plate having a hole drilled through it that would serve as a throttle opening. A determination was then made of the maximum speed the car could attain on a long stretch of hard, level road with this orifice in place. This test was repeated with a number of orifices of different sizes. With the engine removed from the car and connected to an electric dynamometer, tests were run to determine the torque capacity of the engine at varying speeds with each of the orifices in place. Knowing the size of the rear wheels and the gear ratio, the engine speed corresponding to any car speed is accurately known. The torque required to drive the car at any one of these maximum speeds for a given orifice is the torque capacity of the engine at that speed with that orifice, as shown by the dynamometer tests. The results of these tests are shown in Fig. 3. In the curves the engine speed

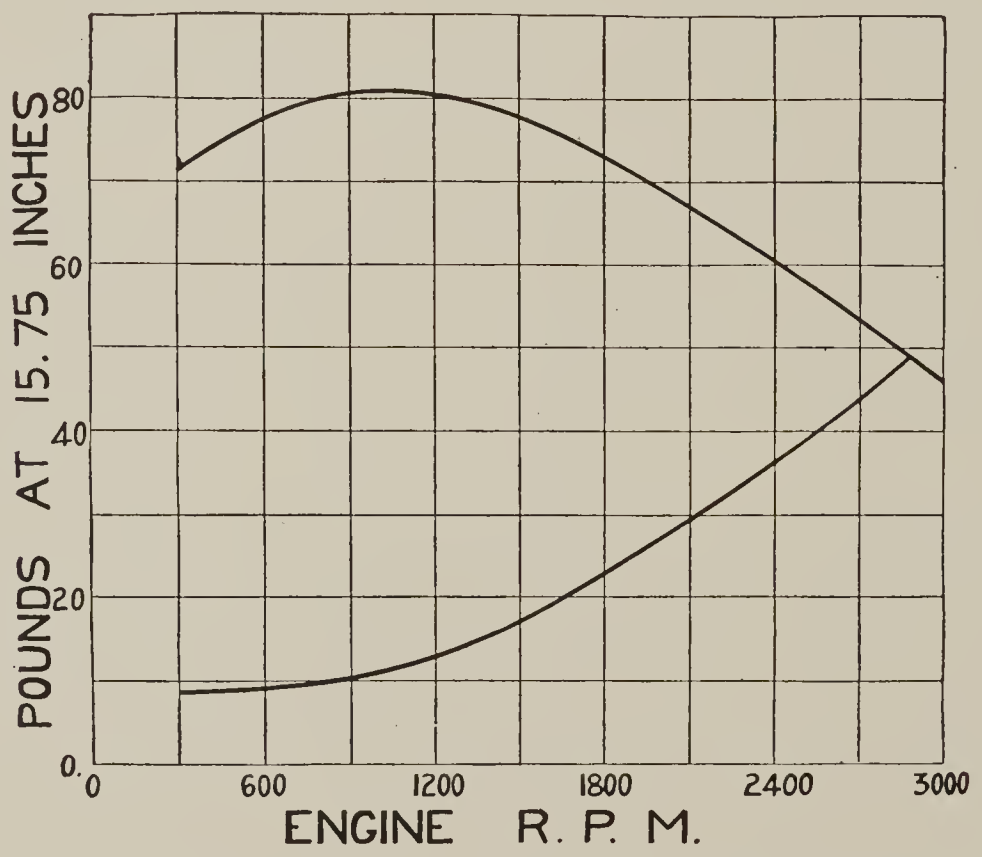

FIG. 3. Relation Between Torque and Speed of Engine

is plotted horizontally and the brake-load is at a radius of 15¾ inches vertically. The upper curve shows the torque capacity of the engine and the lower the torque measured at the flywheel of the engine that is required to propel the car at corresponding speeds.

The distance between the upper and lower curves is therefore

proportional to the reserve power of the engine and represents its ability to accelerate rapidly or climb a steep hill.

In this particular car an engine speed of 1,000 r.p.m. corresponds to twenty miles per hour. It will be noted that at this speed only about 14.7 per cent of the torque capacity of the engine is used when driving on a good road. Any one familiar with the performance characteristics of an engine knows that this fact alone will account for a large reduction in the thermal efficiency obtainable from the engine under ordinary driving conditions. This is such an important consideration that a special series of tests was carried out to show the exact situation.

Efficiency at Different Loads

It is well known that the brake thermal efficiency of an engine varies from zero at no load to a maximum which occurs at a little less than full load. Engines differ in their ability to perform under different conditions, according to their design, some doing comparatively better at light loads and others at full load. Tests were therefore carried out on the engine previously used, to determine the effect on its thermal efficiency of changing the load.

The engine was installed on the dynamometer and run at 1,000 r.p.m. and at a series of different throttle openings. At each throttle opening a series of tests was run at different carburetor settings, similar to the tests plotted in Fig. 1, and showing the mixture corresponding to highest efficiency at that throttle, together with the corresponding power and efficiency. The brake-load was expressed in terms of brake mean effective pressure, and a curve was drawn through the points showing the highest efficiency at each load. This curve is shown in Fig. 4, and indicates the maximum efficiency obtainable with this engine at each brake-load, the engine running at 1,000 r.p.m. The efficiencies will vary as the speed is changed, so that this curve should be interpreted as applying only to the one speed.

The carburetor was adjusted lean enough to give maximum economy at all loads until the throttle was wide open. After this point was reached the increases in power had to be obtained by enriching the mixture, until the full power was obtained. These richer mixtures result in reduced economy, thus causing the curve

in Fig. 4 to show a decided drop as full power is approached. This curve therefore offers one more illustration of the importance of using lean mixtures when high economy is desired.

Fig. 4 shows how important it is to run the engine under a

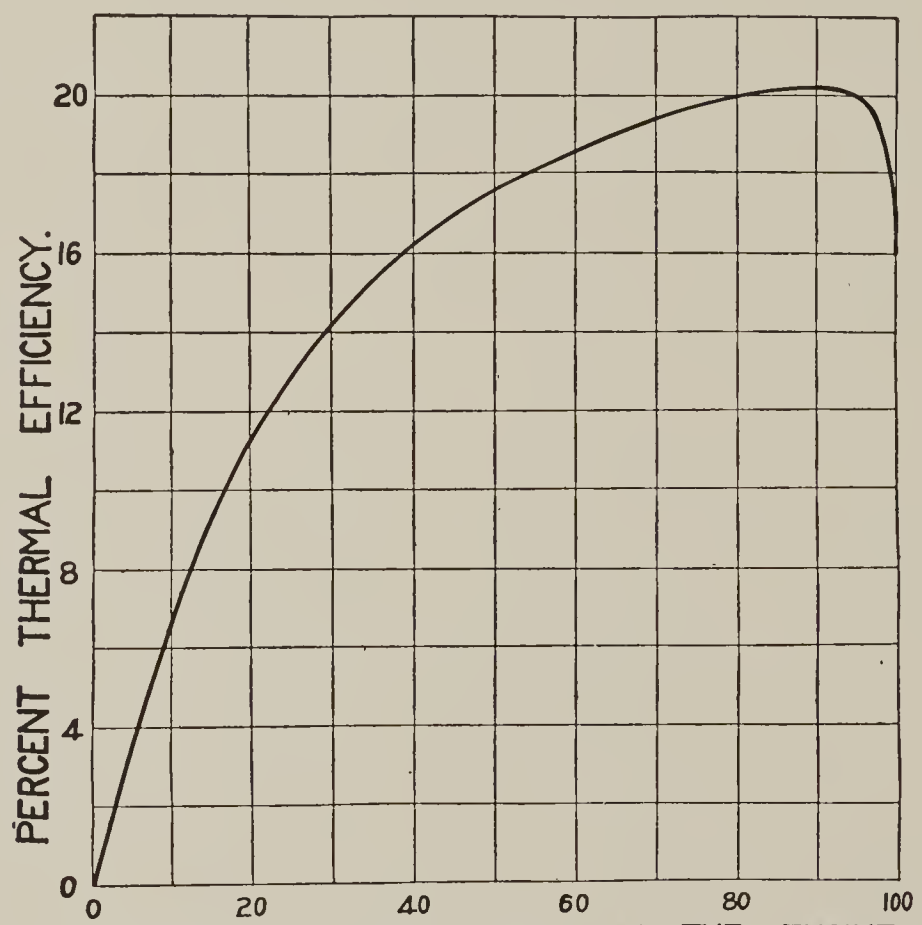

FIG. 4. Efficiency Obtainable at Each Brake-load

comparatively large per cent of its full load capacity. Since the miles per gallon of any car under given running conditions will vary directly with the thermal efficiency of the engine, a change in the load factor on the engine can result in greatly increased economy. This fact was checked in part by installing a different rear axle ratio and noting the change in the car economy. The standard ratio was 4⅞ to 1, and resulted in a load factor of 14.7 per cent at a speed of twenty miles per hour. Under these conditions the car could go 28 miles per gallon when loaded so as to weigh 3,100 lbs. A gear ratio of 2½ to 1 would result in nearly twice the former load factor, and Fig. 4 shows that this should result in an increase of about 50 per cent, or 42 miles per gallon. Under test the car actually ran 43 miles per gallon. These tests were all made with a carburetor equipped so as to make starting easy in cold weather, through the use of a dash adjustment.

Advantages and Disadvantages of an Additional Gear Speed

Efficiency and a great ability to accelerate cannot be obtained at the same gear ratio. The former requires that the engine run at a high per cent of its torque capacity and the latter requires the other extreme. We cannot afford to compromise the delightful activity of our cars. On the other hand I feel confident that the first company to produce a car with the activity we are used to and which is also capable of going more miles per gallon than any other car of its weight in the country will become both rich and famous. We can accomplish this if we have four speeds forward. Third speed could be called the "power" or "speed" gear and the fourth the "economy" gear. Such an arrangement would be a benefit in the following ways:

It would greatly increase the miles per gallon.

It would reduce the engine vibration at the common touring speeds.

It would increase the speed at which one could tour with comfort and satisfaction on good roads.

It would enable one to tour at high speeds with the mental satisfaction that would result from knowing that one is not punishing the engine, while any other car at the same speed would be going entirely too fast for its own good.

It would greatly reduce the wear on the engine, thus prolonging its life and reducing maintenance costs.

The disadvantages are the following:

The four-speed transmission would be expensive when sufficiently well made to be quiet on two gears.

The gears would have to be shifted more often.

The possible advantages are therefore fundamental and far-reaching, and the disadvantages are of a practical nature, and though difficult, still I do not feel that they will be beyond our engineers when they really get interested in mastering them.

Our knowledge of how to increase car economy is not yet complete. There are factors influencing miles per gallon that are not mentioned here. This paper is merely a progress report presented at an early stage. I feel, however, that it has gone far enough to demonstrate the value of the study and warrant a conviction that American engineers can be depended upon to produce

cars in the future showing economies that would now seem almost impossible.

In conclusion allow me to repeat that a fuel shortage in the near future is inevitable, but that its ill effects can be greatly lessened by taking the right steps at the present time. By lessening wastes in mining and storing petroleum, by perfecting the processes of making gasoline and especially by developing ways of producing substitute fuels economically and in large quantities, the chemists of the country can help make it possible for future generations to ride in automobiles. In the meantime the engineers will be steadily increasing the economy of our cars and thus adding greatly to the value of each gallon of available fuel.

THE RELATION OF THE CHEMICAL ENGINEER TO THE MANUFACTURE AND APPLICATION OF AUTOMOBILE FINISHES

By C. D. HOLLEY, Ph.D.

Read at the Detroit Meeting, June 20, 1921

Less engineering, particularly chemical engineering, has been devoted to the paint and varnish industry than to any of the other modern industries of similar magnitude. As late as the beginning of the present century, at which time many of us were just beginning our professional careers, it would have been very difficult to have cited or discussed any engineering feature connected with the paint or varnish industry that was worthy of mention. Perhaps some will be inclined to challenge this statement and point to certain of the industries whose products are used in the manufacture of oils and colors, but I refer primarily to the paint and varnish industry in itself.

A late start ofttimes results in increased progress, and this is particulary true of the paint industry. It has outgrown many of its rule-of-thumb methods and procedures and is now using some genuine engineering in the manufacture of paint, enamel and varnish products and in their application.

The rapid developments in the automobile industry, especially as related to quantity production, have necessarily had their effect on the manufacture of paints and varnishes and have been perhaps the most potent influence in the development of this industry from an engineering standpoint.

Although the paint industry is frequently considered as separate from the varnish industry, both are closely connected and in the larger plants they are in fact regarded as separate departments of the same industry. The modern paint and varnish plant compares favorably as to size with the representative plants of other industries. The larger plants have a daily production capacity of 10,000 gal. or better of varnish and 12,000 to 20,000 gal. of paints and enamel products.

In the manufacture of the ordinary types of paint, of which house paint is a typical example, the liquid or vehicle is essentially raw linseed oil, and the procedure of combining the pigments and the oil is rather elementary. In automobile finishes raw linseed oil as such is but little used, the vehicle being always in the nature of a varnish or grinding japan—*i.e.*, composed of heat-treated oils, fused resins, metallic driers and volatile thinners, of the kinds and in the quantities the manufacturer considers necessary.

After the gums and oils have been "run" on the fire for the requisite length of time, which varies with the character of the products used and the requirements, the kettles are removed from the fire and allowed to cool until the temperature has dropped sufficiently to permit the addition of the volatile thinners. In Fig. 1

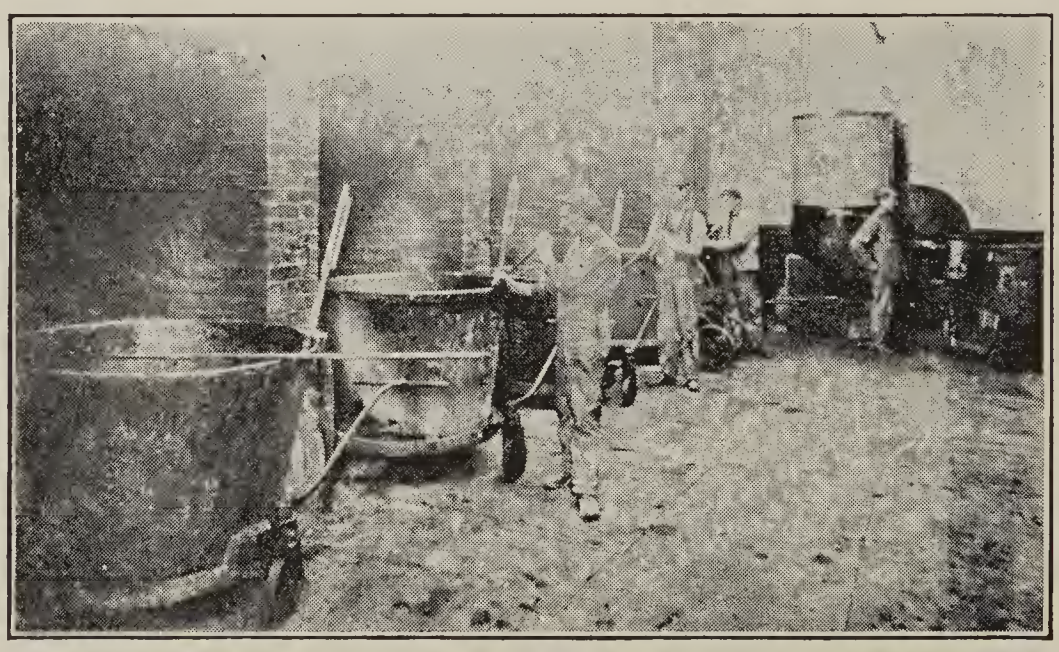

FIG. 1. The Old Type of Varnish-making Installation

is shown the older but still common type of varnish stack under which the gums are melted with no attempt to recover volatilized fumes. The kettles shown in Fig. 2 are being cooled in the open air. A portion of the melting and cooling room in a modern plant equipped with recovery apparatus is shown in Fig. 3 After the varnish has been thinned and is cool it is run through a press or a centrifugal clarifier and stored to age.

GRINDING PIGMENTS AND COMBINING WITH VEHICLE

The grinding of the pigments with the varnish vehicle for automobile coatings is accomplished in several types of mills. The mill

most commonly used is the flat stone mill, 20 in. in diameter, the stones being water-cooled.

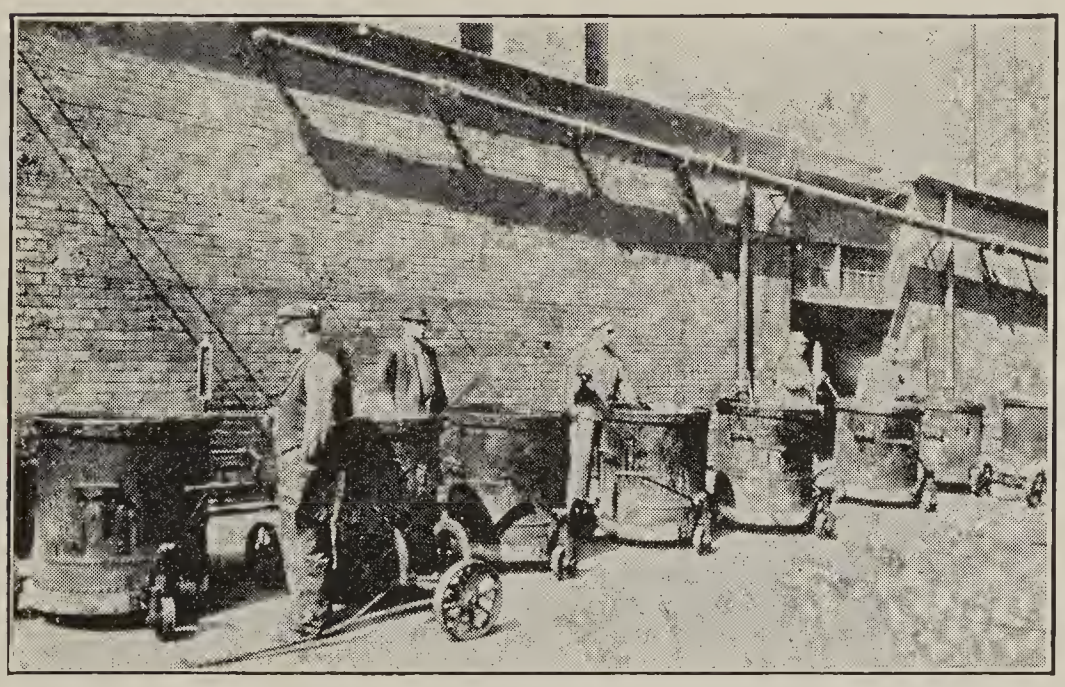

FIG. 2. Allowing Kettles to Cool Prior to Adding the Volatile Thinners

Recently a new type of mill has come into use. This is shown in Fig. 4. It resembles the previous type of mill, but instead of the rolls touching each other, each roll which is of granite is bedded individually in a half round block of granite, the contact between the roll and its bed furnishing the grinding surface.

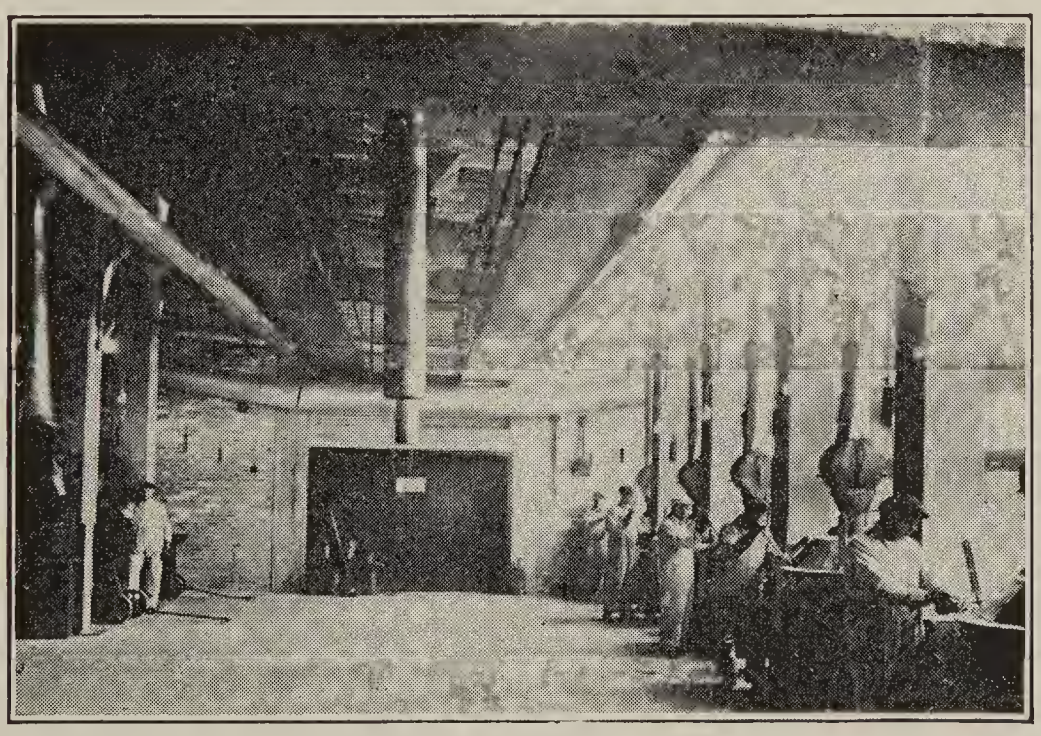

FIG. 3. Portion of Melting and Cooling Room in a Modern Varnish Plant

After the enamel has been ground in the form of a paste, it is thinned by the addition of the requisite varnishes and volatile thinners and then strained to free it from dirt particles or else run

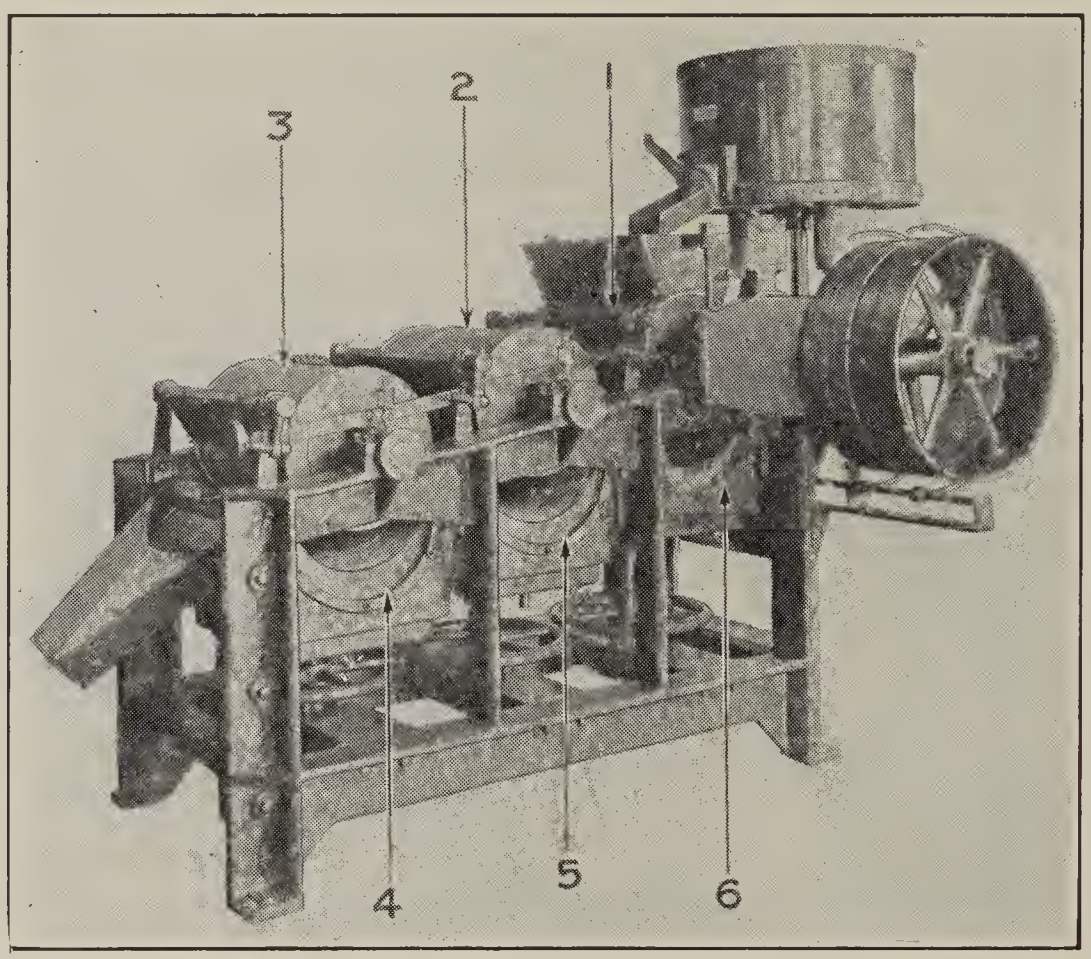

FIG. 4. Three-roll Mill for Grinding Pigments

1, 2, 3—Hard granite rolls, 4, 5, 6—Half-round hard granite beds leaded in cast iron.

through a clarifier. Clear varnishes, baking japans and auto coatings containing pigments of low specific gravity such as carbon or lampblack pigments are now handled by means of a clarifier.

USES FOR CENTRIFUGAL CLARIFIERS

Centrifugal clarification permits the paint manufacturer to prepare many of his automobile coatings free from dirt particles, small "liver" formations and any coarse pigment particles and therefore enables the user to obtain a smooth, uniform finish, free from specks or spots without having to rub down the coats. This treatment also enables the automobile manufacturer to keep the varnish and enamel coatings in his dipping tanks and collecting tanks continually freed from particles that would speck the surface. It has

been the experience of one manufacturer that prior to the installation of such a system more than half of his finished product was returned by the inspectors for further rubbing down and afterward it was reduced to less than 5 per cent. It is very generally conceded that the introduction of centrifugal clarification in connection with modern application devices, such as the use of "floco," has resulted in a saving of more than 80 per cent in labor costs for finishing, to say nothing of the elimination of wastage. Fig. 5 shows a typical installation of a clarification system.

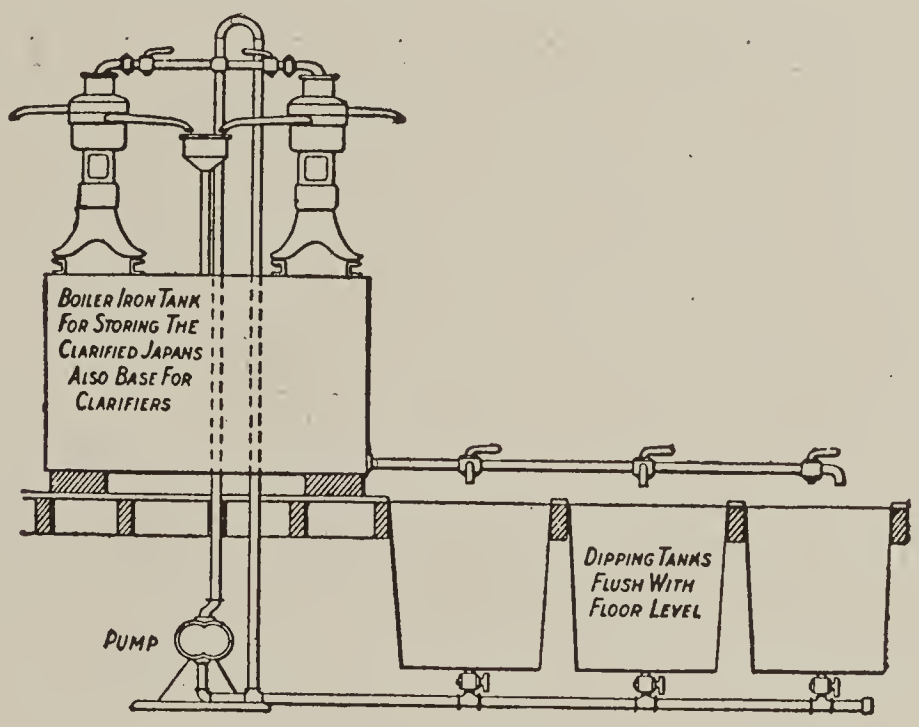

Fig. 5. Diagram Showing Installation of Centrifugal Clarifiers

The pigment materials used in varnish manufacture or the technique of combining the vehicles with the pigments have not been discussed in detail, as these are well known and do not present any engineering practice worthy of mention in the present limited treatment of the subject.

Fume Collection

There is, however, one feature in connection with the varnish industry that deserves special attention. Varnish making is a very old industry and the varnish maker has been content to go about his business without bothering himself about any chemical engineering requirements. Recently he has changed his mind, because in several instances he had his choice of closing down permanently, moving his plant at a heavy financial loss, or getting out of his trouble by resorting to the services of the chemical engineer.

Most varnish plants were built either in a manufacturing section or in the outskirts of the cities away from the residential sections, but with the growth of the cities, many of these plants have found themselves surrounded by residences, the occupants of which object to the large volumes of fumes emitted from the varnish stacks. From 10 to 25 per cent of the weight of the varnish gums used is driven off in the melting of the gums. These products of decomposition pass up the varnish stacks and are disseminated in the air in quantities that sometimes reach several thousand pounds daily.

This has necessitated the installation of an efficient fume-control system whereby these fumes can be condensed as they leave the kettles or be made to enter into a chemical combination and thereby be eliminated. This has required some really ingenious chemical engineering practice, as the problem was not an easy one to solve, because of the physical and chemical nature of the fumes and because of the fact that the gums are "run" in the varnish kettles at nearly their flash point; any undue disturbance in the equilibri-

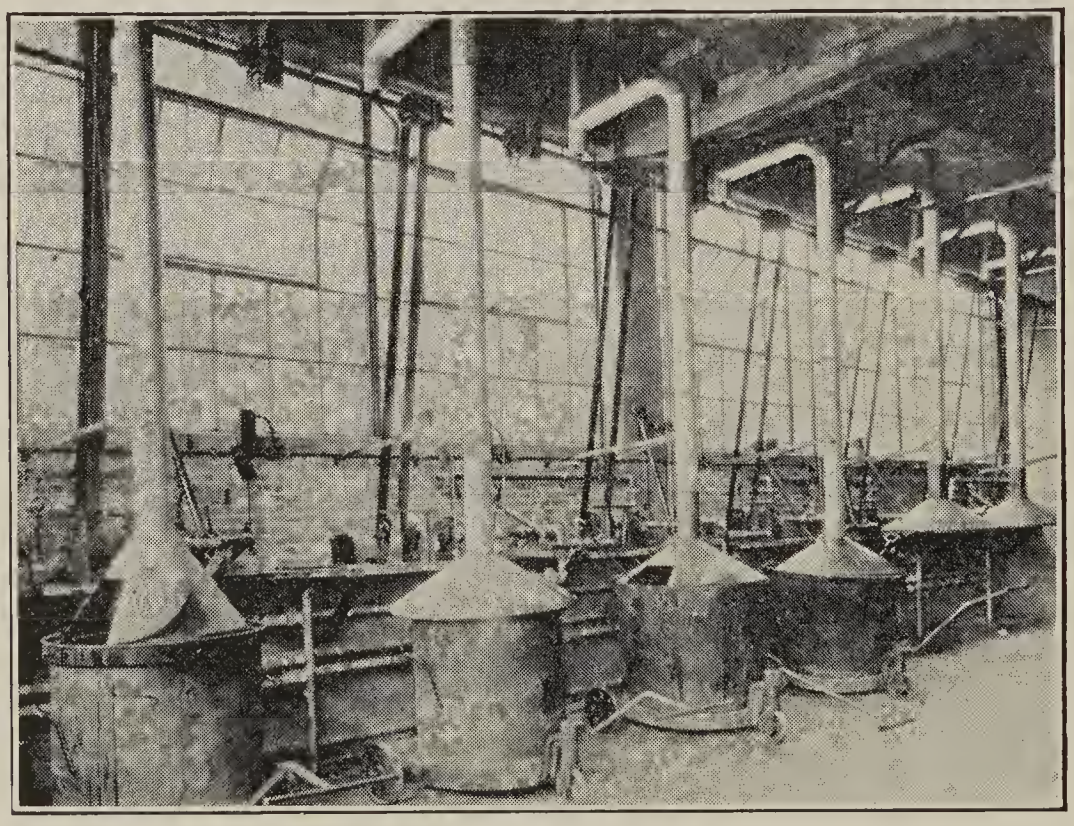

FIG. 6. Thinning Recovery Apparatus

um of the gases in the kettle often meant a bad fire. Two views of recovery apparatus are shown in Figs. 6 and 7. These installations have proved quite successful, affording usable by-products,

and in several instances have permitted a 50 per cent reduction in the insurance premiums and, not least, have permitted the varnish maker to continue the manufacture of his products undisturbed by the authorities.

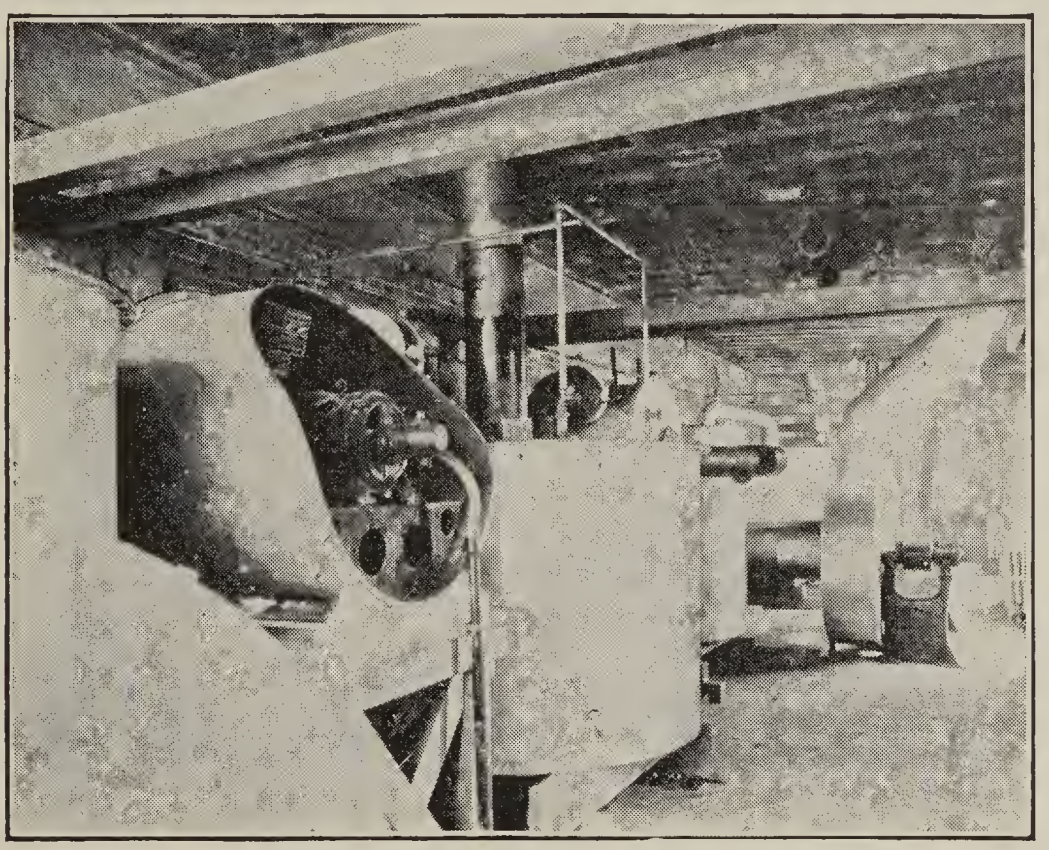

Fig. 7. Varnish Fume Recovery Apparatus

Application of Automobile Finishes

The systems of finishing and the methods of application developed by the automobile industry have a very close relation to modern engineering practice. There are many variations in details in the leading automobile plants depending on the experiences of the finishers in charge, on the production schedule as related to the floor space available, on the price allowed for the job and especially on the labor- and time-saving devices installed. The last named have resulted from the research of chemical and other engineers.

Possibly no two devices have done so much toward reducing the cost of auto coatings as the "spray" and the "floco." Their introduction and use have accomplished wonders in the automobile industry in the way of quantity production, and due credit should be given the chemical engineer in bringing about the results obtained. The amount of work that can be accomplished by the spray over hand brushing varies considerably, depending upon the nature

of the parts and the conditions under which the work is done. It is conservatively estimated that it does the work from a minimum of twice as fast and ranging from this figure up to seven times as fast as can be done by an experienced brush hand. It is used for applying the undercoatings on bodies, quite generally for all chassis work and more or less on the wheel jobs. The "floco" is used for flowing on the finishing coats and in some instances the color coats on bodies and can be used on fenders and hoods as well. On open body work the cost of application has been reduced to 30 to 40 per cent of the previous cost.

Dipping, Baking and Drying

The application of baking japans by dipping and then baking at comparatively high temperatures was well understood before the automobile industry became a commercial factor. Generally the parts dipped were quite small and could therefore be easily handled. When the automobile plants went into quantity production, the application of baking japans to fenders, hoods and other parts together with the subsequent baking operations required extensive installations. Our present-day procedures are the result of extensive engineering research. Much ingenuity has been expended in labor-saving devices for dipping and protecting the dipped articles from dust while draining and then conveying them mechanically

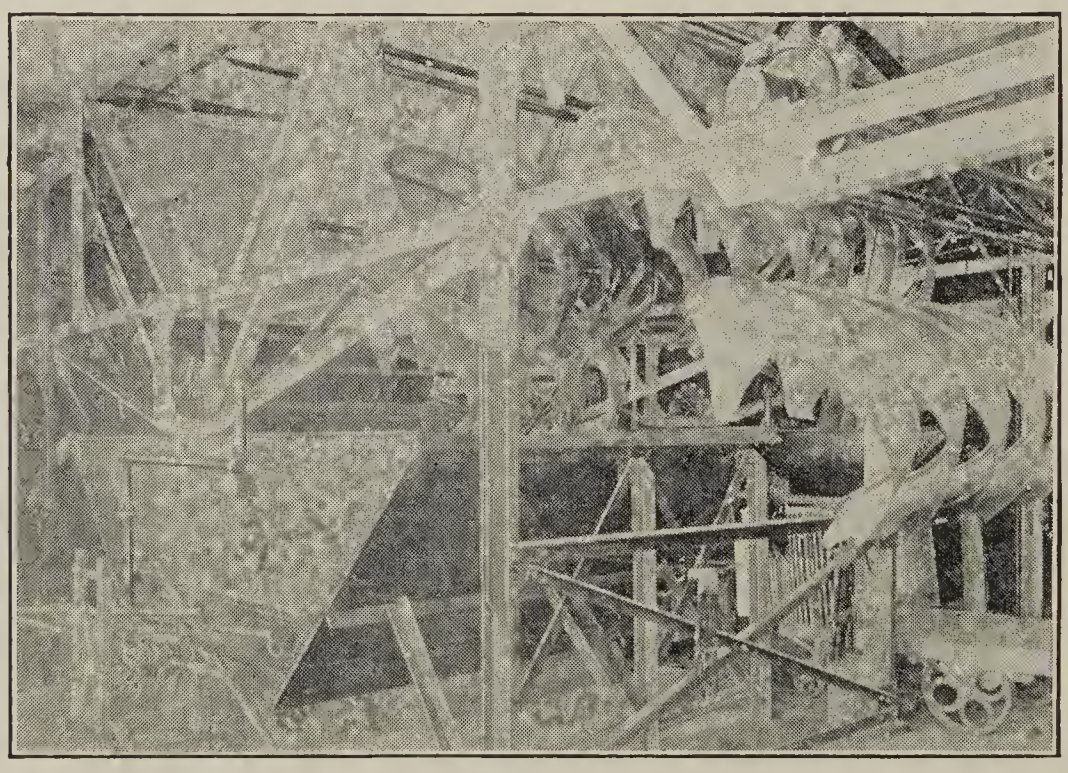

Fig. 8. Dipping Automobile Fenders Prior to Entering Baking Ovens

through the ovens. An intermittent conveyor and a dip used for fenders are shown in Fig. 8.

The time of baking has been shortened by systematic temperature control. The dangers of the old direct gas-fired oven with which there was always a risk that a burner might go out, fill the oven with gas and the mixture explode with disastrous consequences from ignition with another burner have been eliminated. The indirect method of heating in which each burner is inclosed in a separate combustion box with a separate vent from the oven is reasonably safe and does not contaminate with soot and other foreign particles the articles being baked. More recently electric baking ovens have come into extensive usage. I shall hold no brief for either the gas or the electric. Each have their advantages and disadvantages. There is still room for considerable improvement; in the larger baking installations the temperature is not as uniform as desirable throughout the cross-section of the oven to get maximum production. Much has already been done to overcome this trouble, and it appears to be only a question of time when a closer uniformity will be obtained.

The drying time of paint, enamel or varnish varies with atmospheric conditions and, since it does vary, it necessarily follows that there must be at least one definite condition under which the coating in question will dry most rapidly and successfully. Moreover there

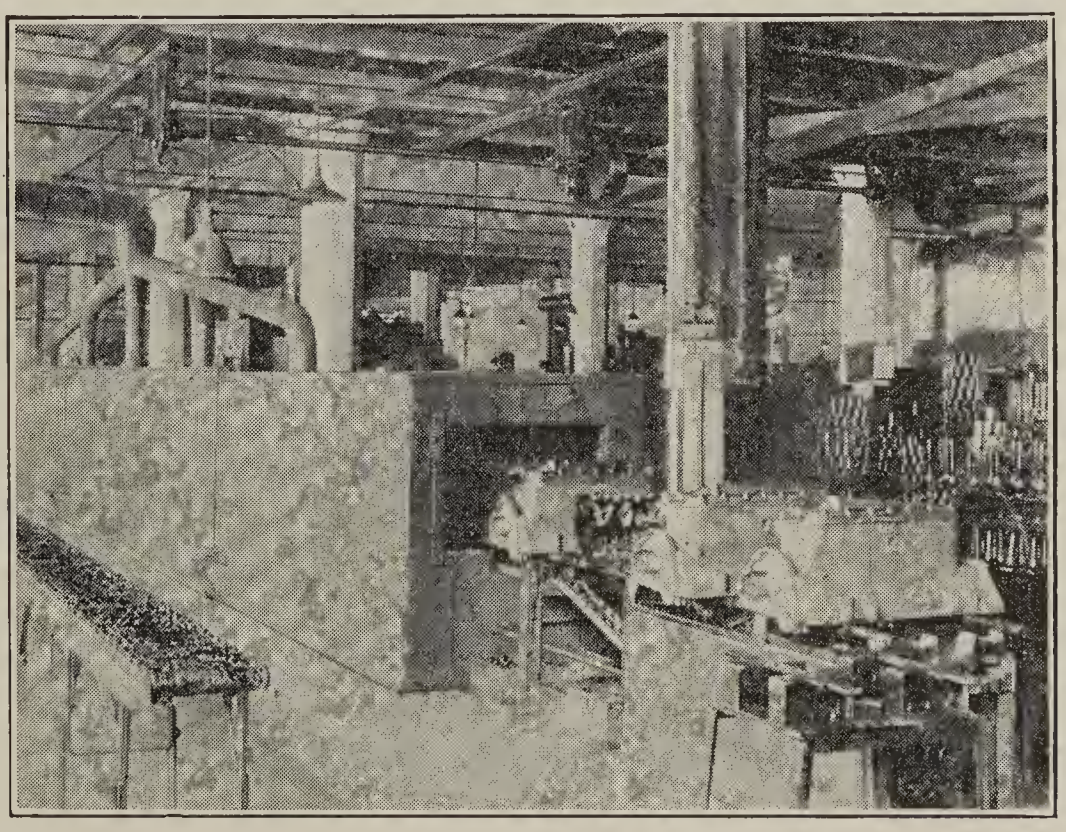

FIG. 9. Exit of Gas-heated Oven for Automobile Engine Parts

are many different coatings to be dried and each coating contains different proportion of oxidizable oils. This, then, is the problem that confronted the automobile engineer and the engineers who have been developing the artificial drying systems.

When artificial drying was first considered, it was the general belief that moisture would retard rather than hasten the drying process. Investigation has proved the contrary, that definite percentages of moisture in conjunction with the heat materially increased the rate of drying over that obtained by the same degree of heat alone. The most successful method of controlling the humidity is by the so-called dew point control, which operates on the principle that the amount of moisture which air can carry at saturation is dependent on the temperature of the air. For instance, having determined that a humidity of 42 per cent at 120 deg. F. is required, it is found that this corresponds to an absolute humidity of 14½ grains per cubic foot, which is the amount present in a cubic foot of saturated air at 90 deg. F. (dew point), and therefore the humidity control device is set at 90 deg. F., the current of air then being raised to 120 deg. F. after passing through the humidifier.

Considerable difficulty was at first experienced in obtaining uniform results with the light colors such as the light blues, yellows, grays and whites. These colors frequently showed marked variation under artificial drying from that obtained by ordinary air drying. More recent developments have proved that by varying the humidity these troubles can be overcome. For example, a light blue job dried at 130 deg. F. with 35 per cent humidity had a greenish overcast, whereas another body with the same varnish, at the same temperature but at a humidity of 45 deg. dried to exactly the same color as an air-dried job. I have cited these instances to show that the artificial drying of an enamel or varnish requires engineering skill.

Conclusion

In conclusion I wish to state that the paint maker and the paint engineer have co-operated whole-heartedly with the automobile and equipment engineers, and to meet the requirements of the various installations I have discussed has been no easy undertaking. It has meant the developing of enamels and varnishes of entirely different characteristics especially as regards their physical properties. The accomplishing of this has been of very material benefit in placing the paint and varnish industry on a more scientific basis.

DETERMINING FACTORS FOR THE LIFE OF A PNEUMATIC TIRE

By WILLIAM G. NELSON

Read at the Detroit Meeting, June 23, 1921

There are five very important and very decisive factors for determining the life of a pneumatic tire. Each has a direct bearing upon the other and a weakness in any one will prove a deathblow to the ultimate mileage which a tire is supposed to give. These five factors are: Rubber and compounding materials, fabric, construction, vulcanization and usage.

Rubber and Compounding Materials Used for Tires

The rubber and compounding materials are comprised of rubber, fillers, softeners, accelerators and vulcanizing agents. A mixture of rubber, sulphur and other materials is called a compound. There are various kinds of compounds used in a tire, as tread, carcass friction and skim coat, breaker friction and skim coat, and side wall. The tread must have good wearing qualities, good appearance and co-ordination with the carcass. By this last phrase is meant the ability to adhere properly to the remainder of the tire. Good wearing qualities are obtained by properly compounding suitable materials and curing agents with high-grade wild or plantation rubber. The most finely divided fillers, such as zinc oxide, gas- and lamp-black and similar mineral fillers, are extensively used due to their microscopical fineness, which gives high tensile strength, good stretch and resistance to abrasion, cutting and aging. Friction and skim coat stocks are so compounded as to give good adhesion to the fabric and a cushioning effect between the plies of fabric. These stocks are composed almost entirely of rubber, softeners, sulphur and accelerators. The vulcanizing agent, which is sulphur, and accelerators are, excepting the rubber, the most important parts of a compound. An accelerator is a material which accelerates the chemical combination of the sulphur with the rubber; since their action is so erratic in mixing, calendering and vulcaniz-

ing, only experienced men should undertake the handling of these agents. The side wall must have good appearance, as it holds one of the most conspicuous places on the tire. It is used for the protection of the fabric against chafing and moisture. Since it is continually exposed to atmospheric conditions it must have good aging qualities rather than high tensile strength or long stretch.

All compounds that come in contact with another must have good adhesion after vulcanization. The factors that bear upon this condition are: Type of rubbers selected; kind and amount of fillers, sulphur and accelerators; mixing and calendering of the compound; building of the tire, and finally the degree of vulcanization.

Fabric

Fabric is the foundation upon which the tire is built. It is used to give stability and strength. There are two well-known classes of tires: the square-woven fabric and the cord fabric. In the square-woven fabric tire the threads in each ply run in both directions, alternating over and under as in a piece of ordinary cloth. In the cord fabric tire the threads or cords in each ply run parallel with the exception of a few small cross threads, used simply to hold the cords in place while they are being impregnated with the rubber compound. The life of a tire would be greatly increased if internal friction could be eliminated. The internal friction caused by intermittent distortion of the tire in use is the result of the friction of the threads upon one another and the strains and stresses set up in the rubber compound. Naturally the fabric which gives the least amount of internal friction will accordingly give the longest life to the tire. Since square-woven fabric cannot be thoroughly impregnated with rubber compound the places where threads cross will be left bare and at these points flexing will cause a sawing action and the generating of frictional heat.

Influence of Heat on the Life of Tires

It has been demonstrated very clearly by experiment that when the temperature resulting from mechanical action reaches 230 deg. F. vulcanized rubber ceases to function as an adhesive compound, crumbles into minute particles which fail to resume their original condition, causing the compound to lose its function in the tire. This causes separation, weakness, and finally a blowout.

It may be interesting to know that 265 deg. F. is not an uncommon temperature reached in a tire when driven at high speed over the road; this is particularly true of large truck tires. In the case of cord fabric each thread is imbedded in the rubber compound and the internal friction is reduced to a minimum. The ideal condition would be to have each cotton fiber of the thread imbedded in rubber, but of course this is not practical and on account of weaving difficulties has not been accomplished.

Since cord fabric comes closer to the ideal condition, the time is not far distant when it will entirely supplant square-woven fabric in the carcass of the tire. A step in this direction will be made when the cost of producing cord tires is sufficiently reduced to successfully compete with the square-woven tire. A brief summary of the advantages derived from the use of cord tires would include easier riding, due to greater resiliency; saving of gasoline and oil; saving of machinery, and more miles per dollar.

Fabric is also used in the breaker and chafing strips. The breaker fabric is covered with a rubber compound that will act as a binder between the soft-cushion stock and the stiff-tread stock. The breaker fabric is used to give stability to this compound and therefore to decrease the separation between the tread compound and the cushion. The chafing strips are used for protection and reinforcement.

Mixing and Calendering

At this point something should be said about the mixing of the rubber and ingredients, and the calendering or application of the compound to the fabric. There are so many factors that enter into the mixing that they can be only briefly described here. Breaking down of the rubber by mechanical action changes it from a tough, hard state to a tacky, plastic condition. This influences the impregnation of the fabric, tackiness, blooming and other physical qualities, and also the vulcanization. The thoroughness of incorporation of the compounding elements has an influence upon uniform vulcanization and wearing conditions. In order to eliminate to the highest degree the variable conditions inherent to milling, calendering, building operations and vulcanizing it is necessary to have every process standardized and a rigid inspection to hold to a minimum the factor of the human element. Therefore all reputable manufacturers analyze thoroughly all compounding materials

and rigidly inspect all fabric before these elements enter into the tire and also carefully control the degree of vulcanization in the finished product.

Tire Construction

Tire construction is an art in itself. It is like the building of a machine and just as much care must be used in designing a tire as is used in designing a finely adjusted machine. As nearly every tire is built on an iron core and is vulcanized in a mold the space occupied by the tire is constant and is filled with a unit composed of many variables. Therefore when the fabric is frictioned and skim coated it is held to a gage of a maximum or minimum variation of 0.002 or 0.003 in. Likewise all other parts as top cushion, breaker, tread, bead and side wall are held to a maximum or minimum gage. The proportion of the fabric to the rubber compound must be properly balanced. The addition of an extra ply or the increase of the thickness of rubber compound may destroy this balance and materially weaken instead of strengthen the tire. It has been demonstrated many times by actual service tests that the correct distribution of rubber compound in the tire will increase its life several thousand miles; or the changing of the sulphur one half of one per cent in a single compound will cause an equal variation in the mileage. There are many faults in a finished tire that can be attributed to improper construction, as excessive overflow, wrinkling of breaker and plies, incompletely filled molds, and weakness in the beads. These are usually remedied by changing the construction but in some instances the proper results can be obtained by changing the compound, the process of vulcanizing, or redesigning the equipment.

Vulcanization

There is probably no phase of tire manufacture that receives more attention than the vulcanization of the tire, and still there is no phase that is more problematical. The proper degree of vulcanization is an empirical condition existing in the various components of a tire which is determined by results obtained by road tests. Either an under-vulcanized or an over-vulcanized tire will give low mileage; even if a single part, such as cushion, breaker or tread compound, is over- or under-vulcanized, the entire tire will give poor results.

The controlling factors in a compound to obtain this empirical state are the sulphur, accelerators, rubbers, milling and calendering, time and temperature of the cure. Any one of these conditions will materially affect the state of vulcanization. The proper manipulation of these variables is a chemist's job and requires great care, thought and experience. It is absolutely essential for the chemist to have a laboratory fully equipped to make comparative physical and chemical analyses, to develop new compounds and try out new compounding ingredients. Various types of rubbers made by different methods of coagulating, washing and drying have different vulcanizing ranges and optimum cures—that is, the state of maximum efficiency when vulcanized—therefore great care must be exercised in their selection for a compound.

Furthermore the optimum cures of all compounds must be so adjusted that in the finished product every component of the tire has simultaneously reached its maximum efficiency. Excessive milling causes the compound to vulcanize more slowly but more uniformly; decreases the tensile strength, and increases the stretch. These actions can be explained by the breaking down of the rubber molecule into its polymeric stages, each stage having its own particular range and optimum cure with its corresponding tensile and stretch. The slower a compound is vulcanized to its optimum cure the better resistance to aging it will have; therefore low vulcanizing temperature and long time is preferable for quality of product, but owing to the demands of quantity production higher temperatures and shorter times are resorted to. The scientific explanation of the effect of time, temperature and mechanical action upon quality of product is a problem of research and it is high time that some of these problems were given proper investigation by the scientific men of today.

Usage

If the tire is neglected and abused while in service, all the care used in testing and selecting the rubbers and the compounding materials, analyzing the fabrics, standardizing the operations and maintaining an experienced organization in order to make the most uniform and perfect product will be of no avail. A pneumatic tire is designed and built to contain air of an inert gas under pressure, and there are no recommendable substitutes for it on the

market today. The greatest danger that befalls a tire in service is under-inflation. Proper inflation is to the life of a pneumatic tire what proper food is to the life of a living being.

Causes for Premature Failures of Tires

Eighty per cent of the failures in tires can be traced to under-inflation. Briefly the results of under-inflation are early separation in all parts of the tire, rim cutting, abnormal development of frictional heat, greater power and fuel consumption, rupturing of the fabric, splitting of tread and abnormal strain throughout the tire. The Society of Automotive Engineers, the Tire and Rim Association and all the large manufacturers of tires have agreed upon standard pressures to be used in tires and these pressures should be adhered to religiously in order to obtain the highest mileage. Overloading is another abuse that is often imposed upon a tire which causes an early breakdown of the carcass and finally a blow-out. Other causes for premature failures are: Improperly fitting rims, which cause rim cutting, thus exposing the fabric to moisture and chafing; misalignment of wheels, which causes excessive tread abrasion; running over curbs, deep ruts, stones, nails and glass, which causes breaks and cuts in the tread and carcass; sudden braking, which causes tread abrasion and separation; turning corners at high speed, which causes excessive strains on the fabric and later a rupture; overheating, which causes separation, and sun exposure, which causes checking.

The ultimate desire of every motorist is to obtain the most miles per dollar per tire with the advantages of riding on a cushion of air, and the only way for him to obtain his desire and retain these advantages is to use common sense in the use and care of the pneumatic tire.

SOME PROBLEMS IN NON-FERROUS METALLURGY

By J. H. RANSOM

Read at the Detroit Meeting, June 21, 1921

Probably few, if any, commercial metals, no matter how carefully refined, are 100 per cent pure. The commercial alloys made from them are usually no more nearly pure. Besides, much of the alloyed material is now produced by re-melting scrap, such as filings, borings, sweepings, buffings, etc. Such material is usually less pure than that made from the virgin metals because of necessary contamination during previous use; because of its introduction during re-fabrication; and also because the waste materials from alloys of different composition are carelessly allowed to become mixed in the factories where made. Thus aluminum bronze borings may and often do become mixed with those of ordinary brasses and bronzes, thus introducing into the re-melt of the whole at least traces of aluminum which tend to increase as re-melting is repeated, and which finally may become detrimental for certain uses. This as well as other impurities can no doubt be removed, in great part at least, during the process of re-melting and fluxing. But it is doubtful if, in the usual procedure, they are wholly eliminated, in which cases they remain and may seriously injure the quality of the alloy.

A probable case in point is the intercrystalline brittleness of lead. Even in a sample of high purity, when solidified from the molten state, it is almost certain that the impurity would collect in the liquid as the crystals form, just as the salt in water remains in the water as the ice forms. And just as in the case of the salt water the concentration of the impurity in the liquid part will rapidly increase as the crystallization proceeds and, finally, must separate at the boundary of the crystal grains with the last crystals which form. Thus would result an intercrystalline—or intergranular—layer very different in composition, and therefore in properties, from that of the granules and would result in a very decided change in some of the properties as compared with those of the

pure metal. For example, the cohesion between the crystal grains might be greatly modified resulting in a change in tensile strength, elongation, and elastic limit. Besides, under corroding conditions the intercrystalline layer might be more soluble than the main mass of the metal and thus a weakening effect result in the presence of water or salt solutions. There might be, and probably would be, developed a difference in potential between the intercrystalline and intracrystalline material, in which case there would be a greatly accelerated dissolving of the more positive part with a correspondingly rapid change in the quality of the metal, and of its time of service.

Recently there has been described an alloy of copper and nickel, containing about fifteen per cent of the latter, which at times is said to develop intercrystalline brittleness, the reason for which is said to be hard to explain. If it can be demonstrated, however, that impurities are present, or if it is reasonable to assume their presence though in too small amounts to demonstrate, then the explanation of the facts is as easy as in the case of lead, and may even be considered a necessary consequence.

At first it might be thought that the segregation mentioned above would occur only in case the impurity were soluble in the molten metal but became insoluble at the moment of crystallization. No doubt such conditions would result in the most rapid and complete segregation. But there is some evidence, apparently, that changes may take place in solid solution or, at least, in very thoroughly distributed solid mixtures. It seems to have been shown that ferrite in steel diffuses from one place to another, under certain conditions, and collects at or near boundary surfaces. The explanation given involves the changing solubility of the ferrite under slightly changing conditions. If this is indeed established for ferrite it is possible for other metals in solid solution or in intimate mixtures to behave in a similar way with like results.

It would be interesting and perhaps instructive to study polished specimens, both etched and unetched, of a series of alloys by means of photo micrographs taken periodically, at intervals of several weeks, for some years. By photographing the same spot repeatedly any segregations or other changes would be brought to light. The difficulties in doing this would lie in attempting to preserve the surfaces of the specimens for so long a time unaffected by the

gases of the atmosphere. It might be done by keeping the specimens, between examinations, in sealed and vacuous tubes. Possibly such work has been attempted, but if so, my attention has not been called to it.

It is common observation in foundry practice that occasionally castings or ingots made from metals, usually secondary, supposed to be of standard purity are covered or spotted over with colors quite different from those usually associated with the alloy. From the salesmanship standpoint these colors are undesirable since they immediately place the metal under suspicion as being made from inferior materials, and slight defects, which otherwise would not be noticed or would be overlooked, are laid at the door of the colors even to the point of rejection of the metal. To throw light on the causes of these colors and to observe any alteration in properties accompanying the colors two series of experiments were planned and executed.

The first series was of a preliminary nature and consisted in studying the effect of a few of the most common impurities on twenty melts of from twenty to twenty-five pounds each of a brass, copper 80, tin 10, zinc 10. The second series was more extended involving seventy melts of copper 85, tin, lead and zinc each 5, and the use of a half dozen or more impurities. The effect was found for each impurity alone, then for every possible pair and, finally, for every possible combination of three or more (except two or three by oversight). Test-bars were made with which to determine the usual physical properties; a special kind of bar was designed with which to observe any segregation of impurities at right angles, and to judge somewhat of the toughness of the metals. Photographs of those melts containing one and two impurities were made as well as analyses of all the melts. Surface colors were accurately described and preserved with properly mixed metallic paints. The total amount of impurity in the metal was practically always under one half of one per cent, often considerably less. The amount of each impurity was often under one tenth of one per cent, and sometimes as low as this when by itself. In a few cases varying amounts of one impurity were used in different melts in order to study its cumulative effect.

As a result of the work several interesting observations were made. Where a surface-color change is made by one element it

is usually characteristic and easily recognized. Usually, also, the properties suffered by the addition of a single impurity but, in a few cases, these remained unchanged or were improved. In general a combination of two or more impurities produced more color change and greater defects in the properties than the same percentage of one impurity. In a few cases the properties in the presence of two impurities were better than for either impurity alone, and the color was as good as when no impurity was present. A combination of more than two impurities always gave poor properties. The non metals were more injurious than the metals. In all cases the hardness, tensile strength, and per cent elongation were decreased and the yield point increased. In the cases of aluminum and antimony the hardness was increased for small amounts and then decreased below that of the virgin alloy. For different impurities the same amount of change in properties does not result from the same percentage of impurity. This, however, is not always true for certain percentages of a few of the impurities used.

A number of lines of experiment are suggested by the results of the work, but these have not been undertaken. The fact that a second impurity sometimes neutralizes the poor effect of a single one is especially significant from the practical standpoint. Since it is so difficult to remove the last traces of an impurity from a metal or an alloy, and thus prevent segregation, as in the case of the intercrystalline brittleness of lead, it seems possible and reasonable that some second element might be added which would prevent the segregation by forming with the first impurity a solid solution of higher melting point than the matrix, or in some other way preventing the impurity from being forced to the granular surfaces. In other words there might be induced a tendency twards physical homogeneity.

At the present time there does not seem to be any very good standard for the composition of babbitts or bearing metals. Almost every large user of this class of alloys has his own formula which he believes furnishes a superior product. An examination of the composition and microstructure of different commercial babbitts does not warrant the belief that there is great difference between them; but that the supposed difference is a question of handling the material, or that it depends on the personal equation. At present the manufacturers are accustomed to furnish the material asked for without

reference to its quality, and usually, I imagine, of necessity, asking a larger price than would be required if material of proven standard quality could be furnished. What is needed is an investigation into the qualities of all possible babbitt materials, including their wearing and antifrictional qualities, and the practicability of their use. From the list could then be selected a very few which would meet all the requirements of practical use. Education of the buying and selling organizations would soon follow and a clear standardization result.

What has been said in regard to bearing metals applies, but to a smaller extent, perhaps, to solders, especially to those for aluminum. There are many of the latter on the market, some under patent control. Usually they have a zinc-tin or a zinc-tin-lead base. The difficulties found in soldering aluminum are, to some extent at least, due to the thin layer of closely adhering oxide which rapidly forms on the surface even when freshly cleaned, thus preventing the adhesion of the solder to the aluminum. Part of the problem, therefore, involves the discovery of a suitable flux. At the present time fluxes are not usually employed; but, instead, a thin layer of the solder is applied to the surfaces while these are being cleaned with a steel-wire brush. This is a rather slow process and, I imagine, is not as effective in cleaning the surfaces as a proper flux would be. But the problem of the continued strength of the soldered joint, or the question of the "aging" of the solder, is also involved. Recently there was brought to me a soldered joint which had been made some time before. It looked to be sound and strong; but two light blows with a hammer caused a clean separation of the aluminum from the solder. Assurance was given me that at the time the joint was made it was especially strong. Yet similar solders have been in use for a year or more without, apparently, losing any part of their strength. The whole question of the structural changes occurring gradually in certain aluminum alloys, the conditions of the changes, and the methods of preventing them is interesting and important from a practical standpoint and should be more thoroughly understood.

The usual methods of purifying alloys, especially secondary or re-melted material, leave much to be desired. This is especially so with the white-metal alloys. The use of zinc chloride, sal ammoniac, sulphur and rosin is expensive, disagreeable, because of

the fumes, and is very slow. Preliminary work on other methods has been done with good prospect of success in the saving of time and money, and in an improvement in the atmosphere in which the work is being done. No doubt the improvements can be extended and perfected.

About a year ago, largely as a result of war experiences, Sir George Goodwin of the Admiralty staff of the British Empire, gave an address before the British Institute of Metals Society in which he emphasized the need for the navy of lighter metal construction, without the sacifice of other qualities. What was suggested for the naval industry is equally applicable to the airplane industry and, perhaps to a slightly lesser extent, to the automotive industry.

In this address Sir Goodwin suggested or implied that the solution of this problem lay along two lines of investigation, for the solution of which the metallurgist, the engineer and the manufacturer might well unite. And since the non-ferrous metals and alloys are usually less rapidly corroded than the ferrous, and are better conductors of heat, which in condensers and engine-cooling devices is an important consideration, it seems reasonable that the solution of the problem suggested may lie in the use of the former.

The first line of investigation suggested was along that of the constancy of the properties of metals and alloys. By implication, at least, there was also suggested an improvement in the constancy of these essential properties. The engineer knows only too well how difficult it is to guarantee that the properties of industrial iron, for example, are constant throughout any large piece of it. Also he knows of the difficulty of exactly duplicating parts from metal even of the same composition. Added to these is the difficulty of exactly duplicating the composition of metals and alloys. Upon this uncertainty, in part, is based the FACTOR OF SAFETY, usually large, which determines the size of each element in the structure. The factor of safety is, in reality, a quantity of material added to the whole element in order to strengthen a possible weakest point and thus be able to sustain, without fear of failure, the maximum load that may be applied. It is evident that if the metal were of like quality throughout, the excess metal would become, largely, an unnecessary load to be carried throughout the life of the machine. It is said that in order to bring the bicycle to a weight where it could be easily propelled by man the factor of

safety was made lower than in any other machine. To do this the tubing was made from the best stock and was carefully inspected for flaws.

In the last few years a considerable amount of work has been done in improving the strength and the constancy of properties of the bronzes, especially those containing aluminum together with small amounts of other alloying elements. Very encouraging results have been secured; but the field has by no means been exhausted. A more thorough study of the effect of varying the proportions of the elements now being used, and of the use of the less common elements not already tried, may reveal a combination of properties well suited to meet the critical specifications demanded of the three types of machines mentioned above, and these properties may be so constant that the factor of safety may be appreciably decreased without danger of failure. Any decrease in this factor will result in an almost proportional increase in the working radius of the machine for a given power input, and thus relatively a saving in fuel.

Another way in which lightness of construction can be accomplished is in the use of metals lighter than steel or the bronzes. From the standpoint of specific gravity the industrial elements fall into two groups, viz. ,those having a gravity between seven and nine, and those between one and one half and three. In the latter class there are but two metals, aluminum and magnesium. Since the specific gravities of alloys are, approximately, the mean of their components, it follows that alloys having a specific gravity much less than seven can be made only by the use of considerable percentages of either aluminum or magnesium, or of both. Within the last few years, and largely as a result of the needs of the three types of machines already mentioned, a large amount of investigation has been carried on to the end that light alloys may be prepared having physical properties comparable with steel or the metals of the bronze and brass type. The work has not been without its successes, and a number of light alloys are now known which, for some purposes, can replace the heavier and more usual metals and alloys. You all know of the light Dow metal alloy which is supposed to be able to replace the more usual steel in making pistons for automobiles; of the Duralmens which can be hardened much like steel, which resist corrosion fairly well, and

which have other desirable physical properties. There are alloys of aluminum and tungsten which resist oxidation better than those of aluminum and copper, and these are now used to some extent in automobile parts. Alloys of aluminum, copper and tungsten are now used in making propeller blades for ships. Still there are an innumerable number of other combinations and proportions that have not been tried out thoroughly and work along this branch is only in its infancy.

There is some justification, apparently, for the belief that the best alloy is still in the future. In addition to the usual properties associated with high-grade metals the new metal, when discovered, must possess two qualities which are lacking in some of those more recently prepared. In service they must retain their properties through long periods of time, and must also retain them when subjected to the widely changing temperatures demanded in service. The investigation of the last property has scarcely begun, even for the more common metals, and the field is large for any one who wishes to enter it.

MICHIGAN SMELTING AND REFINING CO.

BOILING POINT OF SALT SOLUTIONS UNDER VARIOUS PRESSURES

Derivation of a General Law which Greatly Simplifies the Accurate Determination of Important Data on the Boiling Points, over the Usual Range of Pressure and Concentration, of Salt Solutions Commonly Evaporated in Vacuum Evaporators

By E. M. BAKER and V. H. WAITE

Read at the Detroit Meeting, June 21, 1921

In an earlier paper[1] attention was called to the fact that in the design of an evaporator installation it is necessary to know the elevation of the boiling point of the solution being evaporated in each effect, at the temperature and pressure existing in that effect. It was further pointed out that while the literature shows a large number of determinations of the elevation of boiling points of aqueous solutions, many of these determinations were made at comparatively early dates with crude apparatus, and hence there frequently were wide variations in the values reported. This laboratory announced the intention of proceeding with the determination of the vapor pressure curves of such solutions as are used by the chemical industry and are commonly concentrated in vacuum evaporators. The Division of Chemistry and Chemical Technology of the National Research Council became interested in this work and made it one of its supported projects. The Council desired that the work be carried out to a greater degree of accuracy than was determined for technical purposes, in order that the data obtained might have a higher value for use in purely theoretical studies. To meet this condition, it was necessary to develop an apparatus in which the pressure could be maintained practically constant and in which other sources of error might be kept below a fixed maximum. The limit considered permissable for this work was placed at an absolute error of 0.1 deg. C.

[1] "The Boiling Point of Salt Solutions," by W. L. Badger tnd E. M. Baker, v. xiii, pt. 1, p. 151, also *Chem & Met. Eng.*, vol. 23, No. 12, pp. 569–574, Sept. 22, 1920.

Description of Apparatus

A sketch, partly diagrammatic, of the apparatus used is shown in Fig. 1. The solution whose vapor pressure was to be determined

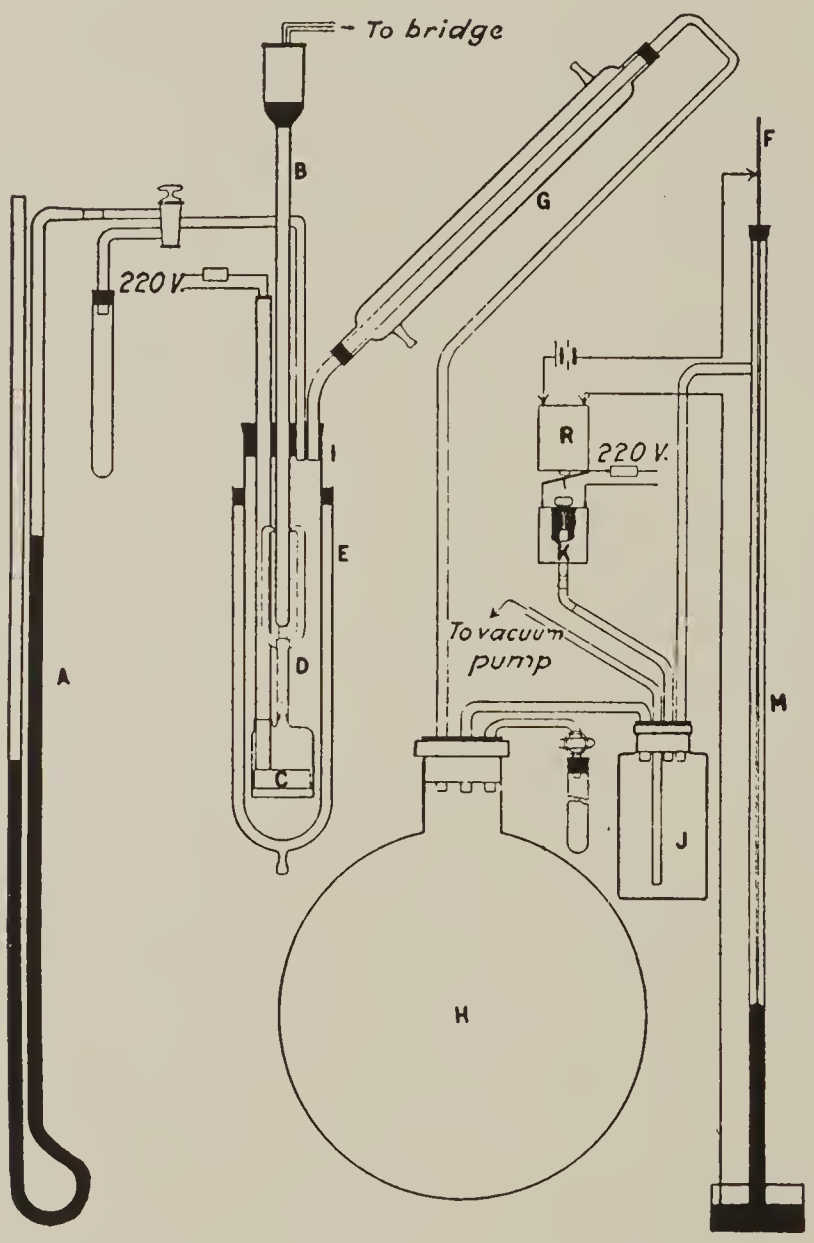

Fig. 1. Sketch of Apparatus

at different temperatures was placed in the glass tube *I* and then heated by an electric current passing through resistance coils in the heater *C*. The current was regulated by an external resistance and the current and voltage used were read on suitable meters. A modified Cottrell[2] pumping tube *D* was slipped down over the heater and used for pumping a mixture of the solution and vapor over the platinum resistance thermometer *B*. The tube *I* was jacketed with a second glass tube, *E*, to minimize the effect of air currents. The vapors coming from the boiling solution passed into a con-

[2] *J. Am. Chem. Soc.*, vol. 41, pp. 721–9 (1919).

denser *G*, to which is connected a large glass reservoir *H*. From *H* a line of glass tubing leads to a small catch bottle *J*, connected to a laboratory water-jet vacuum pump. This catch bottle was also connected to a vacuum regulator, consisting of two parts, a manometer *M* and a needle valve operated by the solenoid *K*. An increase in the vacuum over the value desired would cause the mercury to rise in the manometer and in turn make a contact with the platinum-tipped rod *F*, and complete a low-voltage circuit through the mercury and the relay *R*. This caused the relay to complete a 220-volt direct-current circuit through the solenoid *K*, thus pulling up its armature. The lower end of this armature constituted the plug of the needle valve.

It is necessary to be able to regulate the lift of the needle valve since different openings are required for best regulation at different absolute pressures. This regulation is obtained by screwing the upper end of the solenoid core up or down to the required position. By a proper setting of the pump the vacuum is regulated to a value slightly in excess of that wanted, and the "vacuum regulator" used to give the vacuum desired. The mercury in the regulating manometer oscillates regularly up and down, the magnitude of the oscillations being about 3 mm. The reservoir or vessel of large capacity *H* served to damp these oscillations, and to maintain the vacuum in the boiling-point apparatus at a very constant value. This vacuum was measured by a manometer *A* connected directly into the boiling-point tube, thus insuring that the pressure read was the true pressure under which the liquid was boiling. The manometer was made of 10-mm. glass tubing in order to minimize the effect of capillary action. The variations in pressure in the boiling-point tube were so slight that the bottom of the mercury meniscus in the measuring manometer would show no perceptible movement over periods as long as a half hour, but the center of the meniscus would breathe or oscillate regularly up and down a distance of 0.1 to 0.3 mm. This measuring manometer was mounted against a mirror to aid in eliminating the parallax in reading. The value of the manometer reading was taken by a steel rule graduated in half adjusted so that its bottom edge was just level with the center of the mercury meniscus in the low arm, and the graduated edge of the rule came to the center line of the mercury in the high arm. The reading of the center of the meniscus in the high arm was

taken with the aid of a magnifying glass, care being used to avoid errors of parallax.

Methods of Measuring Temperature and Pressure

A 10-mm. tube filled with mercury was hung beside the measuring manometer, and its temperature read on a mercury thermometer whose bulb extended some distance down in this mercury. The temperature so read was taken as the temperature of the mercury in the measuring manometer. By this means the effect of lag with changing room temperatures was eliminated.

The temperature of the boiling solution was taken by a platinum resistance thermometer *B*. Except where otherwise noted, this thermometer was not immersed in the body of the liquid, but was in the vapor space. The thermometer tube was kept well wetted with solution for a distance about an inch above the platinum coil by means of the pumping tube *D*. The resistance thermometer was constructed according to the method as given by the Bureau of Standards,[3] and was provided with compensating leads. The resistance was measured by means of a bridge with a wall galvanometer. In calibrating the thermometer and at all other times, the resistances corresponding to *A* and *B* in the formula $X = (A/B)\ R$ were each 1,000 ohms, and the same resistance coils were used for *A* and *B* throughout. For adjusting the resistance *R* to balance *X* a precision resistance was placed in parallel with the resistance *R* of the bridge proper. The precision resistance was adjusted to a value slightly greater than *X* and the final adjustment obtained by adjusting the resistance of the bridge. This latter resistance would always be large, at least 500 ohms, so that the accuracy of the bridge as a whole was determined by the galvanometer and the precision resistance. One of the three leads to the thermometer was connected in the battery circuit, and the two other leads were placed one in each of the arms *X* and *R*. These latter two leads were at no time interchanged from the position they occupied at the time of calibration. A compensated aneroid barometer was used for measuring the barometric pressure. This barometer was compared at different times with the mercury barometer of the university observatory, and a calibration curve constructed.

[3] Scientific Paper 407.

Discussion of Sources of Error

The general sources of error that may be experienced in boiling-point determinations have been so well discussed by Smith and Menzies[4] and others that only those relating to this particular apparatus will be treated here.

Pressure and Temperature Control.—The vacuum regulator made it possible to maintain a constant mean difference between the barometric pressure and the pressure in the apparatus for as long a period as was desired. In some determinations the pressure in the apparatus actually oscillated as much as 0.3 mm. from the mean value, but as these oscillations were rapid and extremely regular, it may be safely assumed that their effect on the mean boiling point of the solution was nil. The temperature for all but the most concentrated and viscous solutions would be correspondingly equally constant. For the latter variations as much as 0.3 deg. C. were noted. In these cases the highest values obtained at a given pressure were taken as correct.

Temperature.—The platinum thermometer was calibrated against the temperature of melting ice, of steam above boiling water, and of the vapor above boiling naphthalene. From the resistance obtained at these three points the constants in the formula $R_t = R_0 (1 + \alpha t + \beta t^2)$ were determined. A calibration curve was then constructed using a scale such that 1 mm. corresponded to 0.1 deg. C. The values for temperature as read are calculated to be accurate to within less than 0.1 deg. C.

Pressure.—The pressures as measured by the mercury barometer and manometer were reduced to equivalent readings at 0 deg. C., 45 deg. latitude and sea level, and the values reported have all been so corrected. The steel rule used was compared with other standards and found to check to within less than 0.1 mm. at 25 deg. C. The height of the mercury column could be read as accurately as a mercury barometer. In taking these readings, the difference in height of the top of the meniscus in the two arms of the manometer was taken as the reading. It can be easily demonstrated that if the mercury column is oscillating regularly, the above reading is the true mean value. The mercury used had been purified by nitric acid, followed by a double distillation in vacuo.

Purity of Materials.—The materials used were sufficiently puri-

[4] "Studies in Vapor Pressure," *J. Am. Chem. Soc.*, vol. 32, p. 1412.

fied so that errors from this source could not cause an error of 0.1 deg. C. in the boiling point of any solution used. Dissolved gases, if any were present, would be completely swept out by the ebullistic method used, since about 20 minutes was allowed at each point for the system to come to equilibrium.

Superheat.—Superheating of the liquid was practically impossible, first, because the heat was conducted to the solution through metal, and second, because the solution that came in contact with the thermometer had been pumped by its own steam up the pumping tube onto the thermometer, thus giving time for the vapor and liquid to come into equilibrium with each other. This also eliminated any possibility of the boiling point of the solution in which the thermometer was immersed being raised by the hydrostatic pressure of the liquid.

Accuracy of Complete Apparatus

To test the general accuracy of the complete apparatus determinations of the boiling point of water from 50 to 100 deg. C. were made, using the pumping tube exactly as in the case of a solution so that the thermometer was wet with the water pumped up. These results are presented in Table I. The fifth column of this table

TABLE I

Comparison of Boiling Point of Water at Different Pressures with Values Obtained by Holborn and Henning

Corrected Barometer, Mm.	Corrected Manometer (Vacuum), Mm.	Corrected Absolute Pressure, Mm.	Temperature Observed, Deg. C.	Temperature From Steam Tables (H and H.) Deg. C.	Difference Deg. C.
736.8	613.2	123.6	56.00	56.00	0.00
726.6	485.8	240.8	70.72	70.71	−0.01
740.8	249.9	490.9	88.22	88.20	−0.02
741.0	168.1	572.9	92.29	92.27	−0.02
741.0	127.5	613.5	94.12	94.11	−0.01
741.0	78.4	662.6	96.20	96.20	0.00

shows the corresponding values gives by Peabody's Steam Tables,[5] which are based on accepted standard values of Holborn and Henning.[6] From these results, it would appear that the apparatus has

[5] Eighth edition.

[6] *Ann. Phys.* (4), vol. 26, p. 833 (1908).

an *absolute* accuracy within this range of better than 0.1 deg. C. The accuracy of pressure measurement is believed to be well within 0.3 mm. It is evident that if the mercurial barometer against which the aneroid barometer was calibrated were in error by 0.3 mm., this would have made the measurement of the boiling point of water, at 123.6 mm. pressure, in error by 0.05 deg. C.

Critical Study of Data

The method of making a critical study of boiling point data described in a previous paper,[7] while satisfactory for most technical work, is not sufficiently exact to preserve the accuracy of data which have a probable absolute error of less than 0.1 deg. C. Data of this sort could be obtained by the use of a series of empirical formulas, such as those of Bertrand, but the labor involved in such a method would be enormous. In searching for a simple yet accurate method for studying the data, it was found that if at a pressure p_1 the solution boiled at a temperature t_1, and water boiled at a temperature θ_1 and that at a pressure p_2 the corresponding boiling points were t_2 and θ_2, then for p_n, t_n and θ_n, the following relationship would hold:

$$\frac{t_1 - t_2}{\theta_1 - \theta_2} = \frac{t_2 - t_3}{\theta_2 - \theta_3} = \frac{t_n - t_{n+1}}{\theta_n - \theta_{n+1}} = K,$$

where K is a constant. In other words, if a series of points were plotted on rectangular co-ordinate paper, showing for a given solution the temperatures at which the solution exerted certain vapor pressures plotted against the corresponding temperatures at which water would exert the same vapor pressure, then all the points so plotted would fall more nearly on a straight line than on any other smooth curve that could be drawn. This is essentially Dühring's rule. In 1878 Dühring[8] advanced the theory that if t_1 and t_2 are the boiling points of a substance at two pressures, p_1 and p_2, and if θ_1 and θ_2 are the boiling points of another substance at the same pressures, then $(t_1 - t_2) = q\,(\theta_1 - \theta_2)$ where q is a constant. Curiously enough, while this rule has been largely used for comparing the boiling points of different pure substances with the boiling points of water, it has apparently not been applied to aqueous

[7] W. L. Badger and E. M. Baker, *ibid.*

[8] Neue Grundgesetze sur nationelle Physik und Chemie (erste folge: Leipzig, 1878).

solutions where the solute exerted practically no vapor pressure. The same statement holds true for the more general law of Ramsay and Young.[9]

The accuracy with which Dühring's rule can be applied to aqueous solutions of any strength, provided always that these solutions are not saturated and provided that the solute does not exert an appreciable vapor pressure, has not been generally appreciated. The application of this rule to several solutions is shown by the curves in Fig. 2. This graph shows as ordinates the boiling points of certain solutions at various pressures, and as abscissas the corresponding boiling points of water under the same pressures.

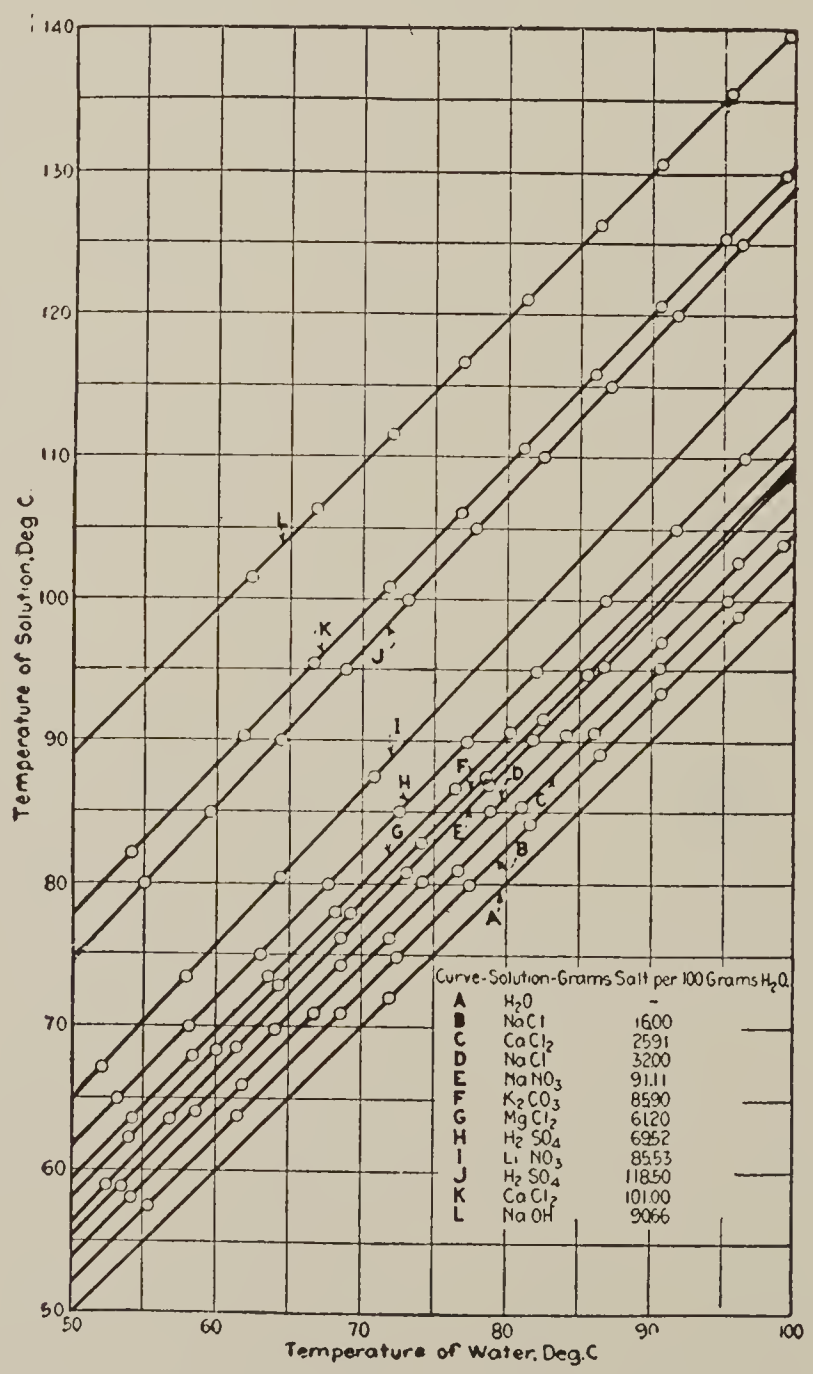

FIG. 2. Boiling Points of Certain Solutions Plotted Against Corresponding Boiling Points of Water Under the Same Pressure

[9] *Z. phys. Chem.*, vol. 1, p. 250.

The boiling point data for this graph were selected rather at random both from the literature and from determinations by the authors. Some of the solutions represented ionize highly, others to a less extent. Some of the solutes are not ordinarily considered to form a series of hydrated particles in solution, others are known to associate strongly. There is a great diversity of the chemical nature of the solutes considered. The actual data plotted are shown in each case by the circles. The curves as drawn are straight lines, and coincide with the data very closely. With few exceptions, the deviation is less than 0.1 deg. C., and in all cases the straight line more nearly represents the data than any other smooth curve that might be drawn. The variation of individual points from the straight line is presumably due to experimental error, and the general agreement of the data with Dühring's rule is most remarkable. That is to say, all these solutions obey the relationship $K = \frac{t_1 - t_2}{\theta_1 - \theta_2}$

Accordingly, if Dühring's rule holds, as this study indicates, in order to define completely and accurately the relationship of vapor pressure to the boiling point of an unsaturated solution of any strength (an infinite number of data), it is only necessary to record two relationships—viz., a curve or table showing the boiling point of solutions of different concentrations at one pressure, for example, atmospheric pressure; and the curve or equation which shows the relation between concentration of solutions and slope of the lines for these varying concentrations.

From these two sets of data, the boiling point of a solution of any composition at any pressure may be at once calculated.

Application of Dühring's Rule

It is evident that in order to obtain the above information, instead of carrying out an indefinite number of determinations of boiling points of solutions at different strengths and pressures, it is only necessary to determine the boiling points of each of a number of solutions of different concentrations at two pressures. One of these pressures will usually be atmospheric. Thus, the establishing of the relation expressed by Dühring's rule has greatly decreased the number of determinations necessary to obtain the information and has simplified the method of recording these data.

To define completely the whole system for saturated and unsaturated solutions, it is necessary to know, in addition to the above, the boiling point of the saturated solution at different pressures, or else the solubility of the solute at different temperatures. With either of these sets of data, a line can be drawn on the chart for the system which will show, at the various solution temperatures, the solubility of the solute. The area to one side of this line will then represent unsaturated solutions for which Dühring's rule will hold, the area to the other side will represent supersaturated solutions and these should not exist under the given conditions; and the line itself will define the boiling points of the saturated solution at different pressures.

We desire to emphasize again that the relationships expressed by Dühring's rule appear to hold, for unsaturated aqueous solutions where the solute does not exert an appreciable vapor pressure, more accurately than data which have been determined, without regard to (1) whether the concentration is high or low, (2) whether or not the solute ionizes, and (3) whether or not the molecules or ions of the solute take up water of hydration or association. It is not at all necessary that the solution be "ideal," to conform rigorously to the law.

It should be pointed out that the curves in Fig. 2 are not parallel (in general) either to each other or to the curve for water, nor is there a definite relation between the slope of the curves and the elevation of the boiling point at any given pressure.

It is planned to use the apparatus and the method as described in this paper in a number of investigations. Two such investigations have already been completed, and are to be published in subsequent papers.[10]

The authors desire to acknowledge the assistance received from the National Research Council, which made possible this work, and of the active interest taken by Prof. W. L. Badger of this department.

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[10] "Vapor Pressure of the System Calcium Chloride-Water," by E. M. Baker and V. H. Waite, page 233. "Vapor Pressure of the System Sodium Hydroxide-Water and of Sodium Hydroxide-Sodium Chloride-Water," by E. M. Baker and A. R. Carr.

VAPOR PRESSURE OF THE SYSTEM CALCIUM CHLORIDE–WATER

The Application of Dühring's General Law in an Investigation of the Boiling Points of Aqueous Calcium Chloride Solutions of Various Concentrations and under Reduced Pressures Affords a Graphic Solution of Some Practical Problems in Vacuum Evaporation

By E. M. BAKER and V. H. WAITE

Read at the Detroit Meeting, June 21, 1921

This paper is a report of an investigation of the boiling points of calcium chloride solutions at atmospheric and reduced pressures. The apparatus used for the determinations and the method of making the critical study are those described in a previous paper by the same authors.[1]

Five solutions of the following concentrations were investigated:

(1) 141.3 g. $CaCl_2$ per 100 g. H_2O.
(2) 101.0 g. $CaCl_2$ per 100 g. H_2O.
(3) 68.86 g. $CaCl_2$ per 100 g. H_2O.
(4) 25.91 g. $CaCl_2$ per 100 g. H_2O.
(5) Saturated solution.

The range of pressures over which the boiling points of the system were studied was from 100 mm. to 760 mm. absolute pressure.

Chemically pure calcium chloride was used for these determinations. Solutions were made up of about the concentrations desired, and the boiling-point curves were determined by the method described. In the case of the more dilute solution a sample of this liquor was then poured into a glass-stoppered sample bottle, which was then sealed with paraffin and held for analysis. In the case of the more concentrated solutions this method could not be used,

[1] "Boiling Point of Salt Solutions Under Varying Pressures," by E. M. Baker and V. H. Waite, p. 223; also *Chem. & Met. Eng.*, vol. 25, No. 25, p. 1137, Dec. 21, 1921.

since on cooling the $CaCl_2$ would partly or completely crystallize, often breaking the containing bottle. For these solutions the sample was taken by pouring a portion of the solution, while still hot, into a tared weighing bottle containing a weighed amount of water. The bottle was then weighed, sealed and saved for analysis. The results of the analysis were calculated back to the original concentration of solution. The standard gravimetric method for chlorine, using $AgNO_3$, was used for determining the concentration of the various solutions. The solutions were tested to determine if any HCl had resulted from hydrolysis and had been given off with the vapor. Hydrolysis was found to be negligible. To make an error of 0.1 deg. in the boiling point the concentration as determined would have to be in error by 0.25 g. of calcium chloride per 100 g. of water, at the range where the boiling point changes most rapidly with a given change of concentration.

Procedure for Concentrated Solutions

Work on unsaturated solutions would have been carried to even higher concentrations than was done, if these solutions were not so viscous that there could be no assurance that at higher concentrations they would be of uniform concentration throughout.

In determining the boiling-point curve for the saturated solution it was necessary to immerse the platinum resistance thermometer directly into the solution, as the solution was so extremely viscous that the pumping tube could not be made to work. Except for immersing the bulb of the thermometer in the solution, the method used was the same as for the unsaturated solution. Temperatures were taken both for ascending and descending pressures with an excess of solid $CaCl_2$ in the boiling-point tube in order to eliminate the possibility of supersaturation or undersaturation. The experimental values thus obtained for both the saturated and unsaturated solutions are shown in Table I.

Experimental Values and Those in Literature

Most of the data given in the literature on the boiling points of $CaCl_2$ solutions can be classified into two groups:

(*a*) The boiling temperature of solutions of a given strength at various pressures.

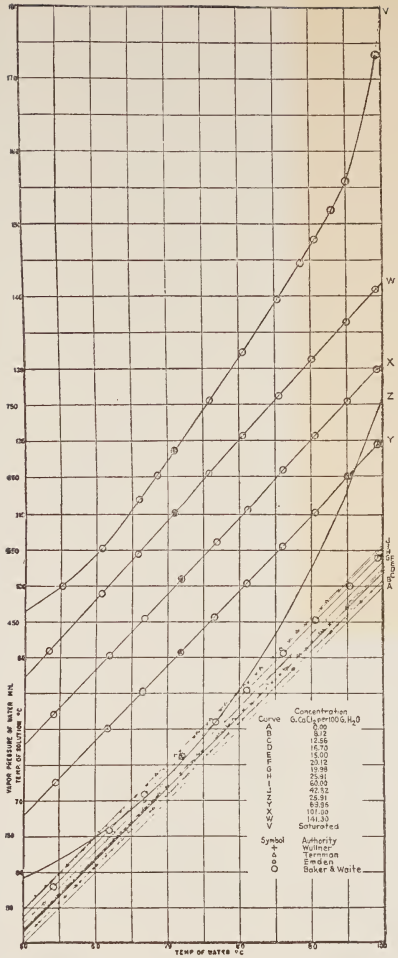

FIG. 1. Boiling Point of Calcium Chloride Solutions Plotted Against the Corresponding Boiling Points of Water Under the Same Pressure

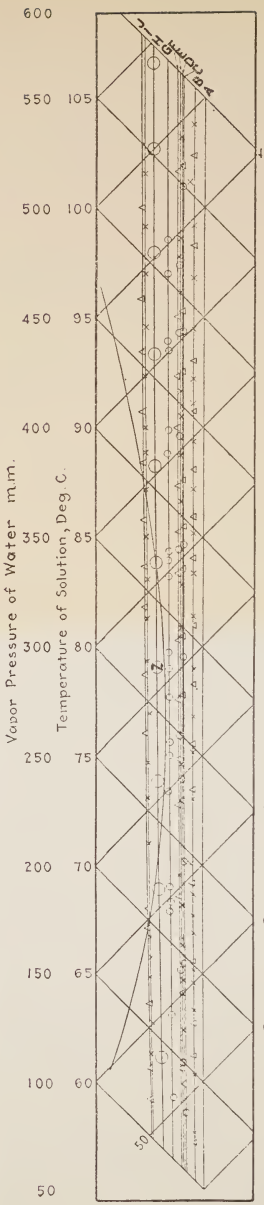

FIG. 1A. BOILING POINTS OF CALCIUM CHLORIDE SOLUTIONS PLOTTED AGAINST THE CORRESPONDING BOILING POINTS OF WATER UNDER THE SAME PRESSURE

Curves A to J from Fig. 1 are here reproduced on a greatly enlarged scale. Explanation of the symbols and data regarding concentration are given in the legend on Fig. 1

TABLE I

VAPOR PRESSURES OF $CaCl_2$ SOLUTIONS AT VARIOUS TEMPERATURES. EXPERIMENTAL VALUES

Concentration: Grams $CaCl_2$ per 100 g. H_2O									
25.91		68.86		101.00		141.30		Saturated Sol.	
Temp., Deg. C.	Pressure, Mm. Hg	Temp., Deg. C.	Pressure, Mm. Hg	Temp., Deg. C.	Pressure, Mm. Hg	Temp., Deg. C	Pressure, Mm Hg	Temp., Deg C	Pressure, Mm. Hg
58.02	113.3	72.66	115.1	82.10	112.9	90.95	108.7	100.05	118 8
65.90	162.7	80.05	161.0	90 28	162.4	99.00	153.6	105.25	154.6
70.90	203.0	85.20	200.8	95.45	202.6	104.51	193.9	111.90	194.6
76.19	254.2	90.70	251.9	100.85	253.0	110.15	243.7	115.20	219.2
81.00	310.0	95.68	308.8	106.10	311.6	115.42	298.7	118.76	242.9
85.45	370.8	100.37	370.5	110.61	371.3	120.61	362.3	125.58	299 8
90.58	452.7	105.56	451.4	115.90	451.7	126.12	442.4	132.32	363.3
95 24	539.5	110.30	537.7	120.65	537 5	131.20	528.9	139.5	440.1
100.00	641.8	114.96	634.2	125.39	635.4	136.37	632.0	144.55	498.7
103.8	738.6	119.35	738.4	129.88	738 8	140.92	733 5	147.90	536 2
.....	....	.....	.....	.....	.....	.....	.. ..	152 75	596.8
.....	....	.....	.....	.....	.....	.....	....	173 4	742.5

(*b*) The boiling temperature at atmospheric pressure of solutions of different concentrations.

Fig. 1 shows the data of group *a* plotted by the method referred to in the previous article — *i.e.*, for each solution of a given concentration, the temperatures at which the solution has certain vapor pressures are plotted as ordinates, against the corresponding temperatures at which water has the same vapor pressures, as abscissas. It is noticeable that the data given in the literature for boiling points of calcium chloride solutions at reduced pressures do not include solutions more strongly concentrated than 43 g. of $CaCl_2$ per 100 g. of H_2O.

Data taken from the literature are indicated by separate symbols for each worker. It will be noted that many of these values as plotted are erratic and do not fall on the curve. However, this is presumably due to experimental errors, as they do fall more nearly on the straight line curves than on any other smooth curve that could be drawn.

In Fig. 1 are also shown experimental data for the solutions investigated by the authors. The curves are lettered to indicate the concentration of each solution. The values for individual determinations are given in Table I and are shown in the graph by the large open circles. In the discussion of the apparatus in the previous paper it was stated that an absolute accuracy of 0.1 deg. C. could be expected in these determinations. The maximum variation of any of the above points from the straight lines as drawn is

0.1 deg. C., while most of the points do not lie more than 0.02 or 0.03 deg. C. from the respective straight lines.

For each concentration of solution represented in Fig. 1 the boiling temperatures of the solutions corresponding to the pressures at which water would boil at 100 deg. C. and 50 deg. C., were read off — *i.e.*, at 760 mm. and 92.3 mm. pressure. From these two readings the slope or tangent of the angle of inclination of each line was calculated. It has been shown that if t_1 and θ_1 are the temperatures at which the solution and pure water will boil under some pressure p_1, and if t_2 and θ_2 are the corresponding temperatures for some pressure p_2, the slope of the line is defined as K in the formula $K = \frac{t_1 - t_2}{\theta_1 - \theta_2}$. These results are tabulated in Table II and shown in Fig. 2.

Explanation of Curves

Fig. 2 shows two curves. In curve A the concentration of solution in grams of $CaCl_2$ per 100 g. of H_2O as abscissas is plotted against the slope of the above lines as ordinates. This curve was extrapolated graphically and the extrapolated portion does not possess the same degree of accuracy as the remainder of the curve. However, in preparing Tables III and IV only that part of the curve was used which was determined by experimental data.

Curve B shows a plot of concentration of solution as abscissas against the boiling point at one atmosphere pressure as ordinates. In addition to the values obtained from Fig. 1, the values given in the literature for the boiling point of solutions at one atmosphere pressure were also plotted on this curve. Curve B is not drawn to pass through a majority of the points as plotted, but the probable relative accuracy of the original data was investigated and after taking into consideration the method of each worker the curve was drawn to pass through the values which are presumably the most nearly correct. It will be noted that the curve is practically determined by our values and those of Johnston[2] and that some values reported in the literature differ widely from the curve.

From the curves of Fig. 2, corresponding values were read for concentration of solutions, boiling point at one atmosphere pressure (boiling point of water 100 deg. C.) and K, the slope of the

[2] See Bibliography, page 242.

lines. These data, which are tabulated in Table III, completely define the boiling points of unsaturated calcium chloride solutions between the two limits given.

If θ is the temperature at which water has any vapor pressure P, and if t is the temperature at which a solution also has the vapor pressure P, then $\theta = 100 - \frac{t_1 - t}{K}$, or $t = t_1 - (100 - \theta)\ K$, where K is the slope of the line for the solution of the given concentration, and t_1 is the temperature at which this solution would boil under one atmosphere pressure. Thus if the constants K and t_1 are known for the given solution, with the aid of steam-tables it is easy to calculate the boiling point of the solution at any pressure. By the use of the above formula, and substituting the respective values of K and t_1 for each of the concentrations of solution tabulated in Table III, and 50 deg. for θ, the temperatures at which these solutions would boil at 92.3 mm. (boiling point of water 50 deg. C.) were calculated. Fig. 3 was plotted from these data and the boiling points of the solutions at 760 mm. pressure,

TABLE II

RELATION OF CONCENTRATION OF $CaCl_2$ SOLUTIONS TO SLOPE OF CURVES IN FIG. 1, AND TO BOILING POINT AT 760 MM. PRESSURE. VALUES READ FROM FIG. 1

Concentration, in per Cent	Concentration, (Grams $CaCl_2$ per 100 G. H_2O)	$K = \frac{\text{Slope } t_1 - t_2}{\theta_1 - \theta_2}$	Bp. at 760 Mm.
20.58	25.91	1.020	104.78
40.78	68.86	1.047	120.18
50.25	101.00	1.058	130.70
58.56	141.30	1.092	141.90

the latter data being tabulated in Table III. The ordinates of Fig. 3 show the temperature at which the solutions would boil under some given pressure, plotted against the temperature at which water would boil under the corresponding pressure, as abscissas. For each of the solutions shown, the boiling points at 760 mm. and 92.3 mm. (boiling points of water 100 deg. C. and 50 deg. C.) were plotted, and straight lines were drawn between the two intermediate points. The corresponding curve for the saturated calcium chloride solution was also plotted directly from the

experimental data. As here reproduced the scale is too small to permit Fig. 3 being directly used as a source of data, but it may

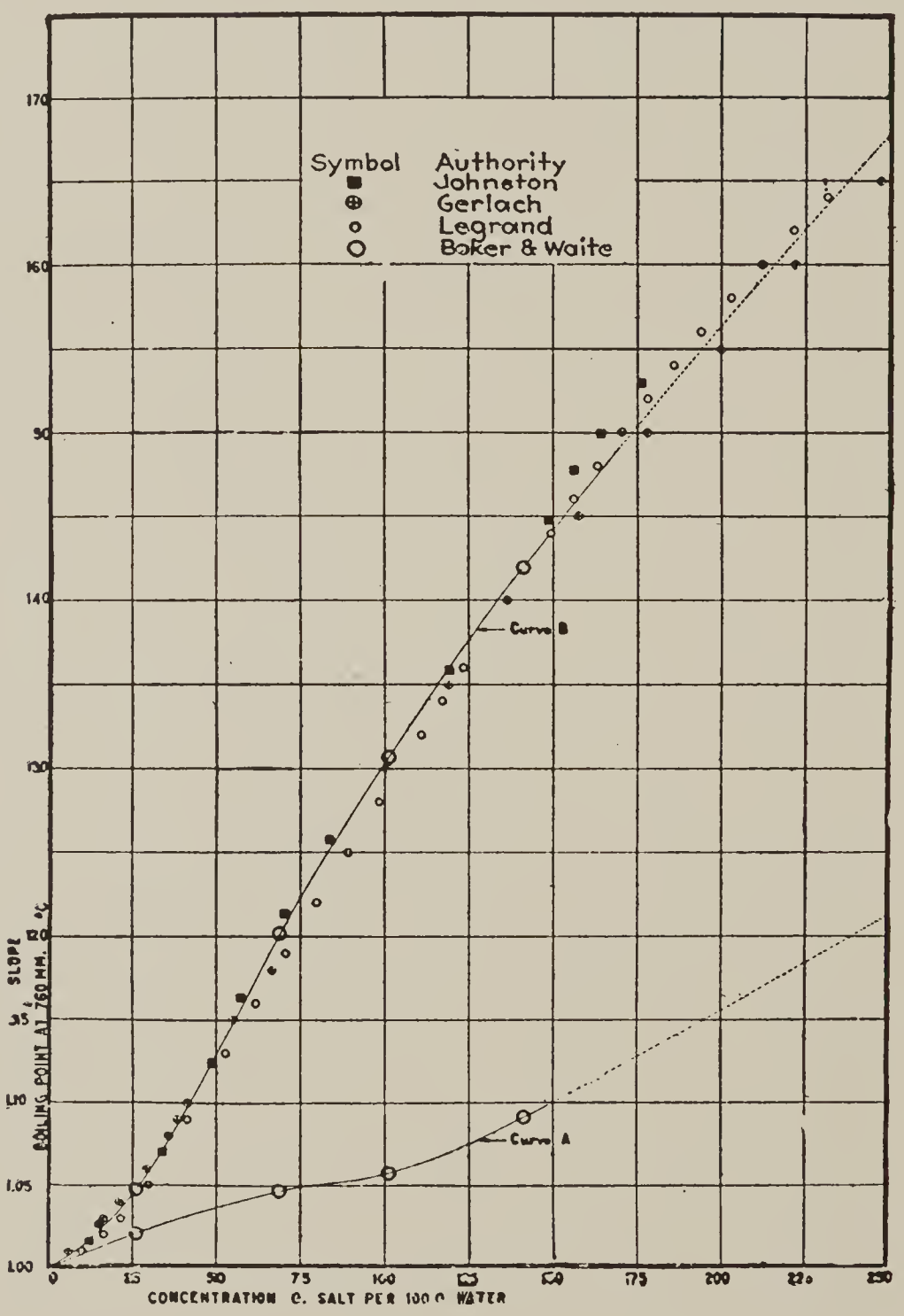

FIG. 2. Curve *A*. Concentration of solution plotted against slope of lines in Fig. 1. Curve *B*. Concentration of solutions plotted against boiling points of solutions at 760 mm.

be easily reconstructed on a large scale from the data of Table III. However, numerous values were read from this figure, and these are reproduced in Table IV, which shows the temperature at which calcium chloride solutions of various concentrations would have

certain vapor pressures, between the limits of 100 mm. and 760 mm. pressure.

Since the curves *A* and *B* of Fig. 2 are based on comparatively

TABLE III

RELATION OF CONCENTRATION OF $CaCl_2$ SOLUTIONS TO BOILING POINT AT 760 MM. PRESSURE AND TO THE SLOPE *K*. VALUE. READ FROM FIG. 2

Concentration (Grams $CaCl_2$ per 100g. H_2O	Slope $K = \frac{t_1 - t_2}{\theta_1 - \theta_2}$	Boiling Point at 760 Mm. (Bp. of H_2O = 100 Deg.	Boiling Point at 92.3 Mm. (Bp. of H_2O = 50 Deg.)
10	1.008	101.30	50.90
20	1.016	103.20	52.40
30	1.023	105.85	54.69
40	1.030	109.25	57.75
50	1.0365	112.90	61.07
60	1.043	116.70	64.55
70	1.0475	120.60	68.22
80	1.0505	124.00	71 47
90	1.053	127.25	74.60
100	1.057	130.35	77.50
110	1.063	133.35	80.20
120	1.0705	136.20	82.67
130	1.080	139.05	85.05
140	1.0905	141 65	87.12
150	1.101	144 20	89.15

few values determined by us, the same accuracy is not claimed for the data on the system as a whole, as tabulated in Table IV, as for an individual determination. The probable maximum error of the latter is 0.1 deg. C., while the corresponding error of values in Table IV may reach 0.2 or 0.3 deg. in extreme cases. An absolute accuracy of this order is quite sufficient for practically all technical purposes.

It will be noticed that the vapor pressure curve of water (data from Peabody's Steam Tables, 1910) is also plotted in Fig. 3. This curve may be used to give directly the vapor pressure under which a given solution will boil at a given temperature and *vice versa*. For instance, to find the vapor pressure corresponding to the boiling point at 90 deg. C. of solution of 100 g. $CaCl_2$ per 100 g. of water, extend across horizontally from 90 deg. on the temperature ordinate to the curve for the given concentration. Then, extending down vertically from this intersection, the temperature at which water would boil at the same pressure is found to be 61.85 deg. C. Or, if the pressure is read corresponding to the intersection of this abscissa with the curve for the vapor pressure of water, this pressure is found to 162.3 mm. and is the pressure sought.

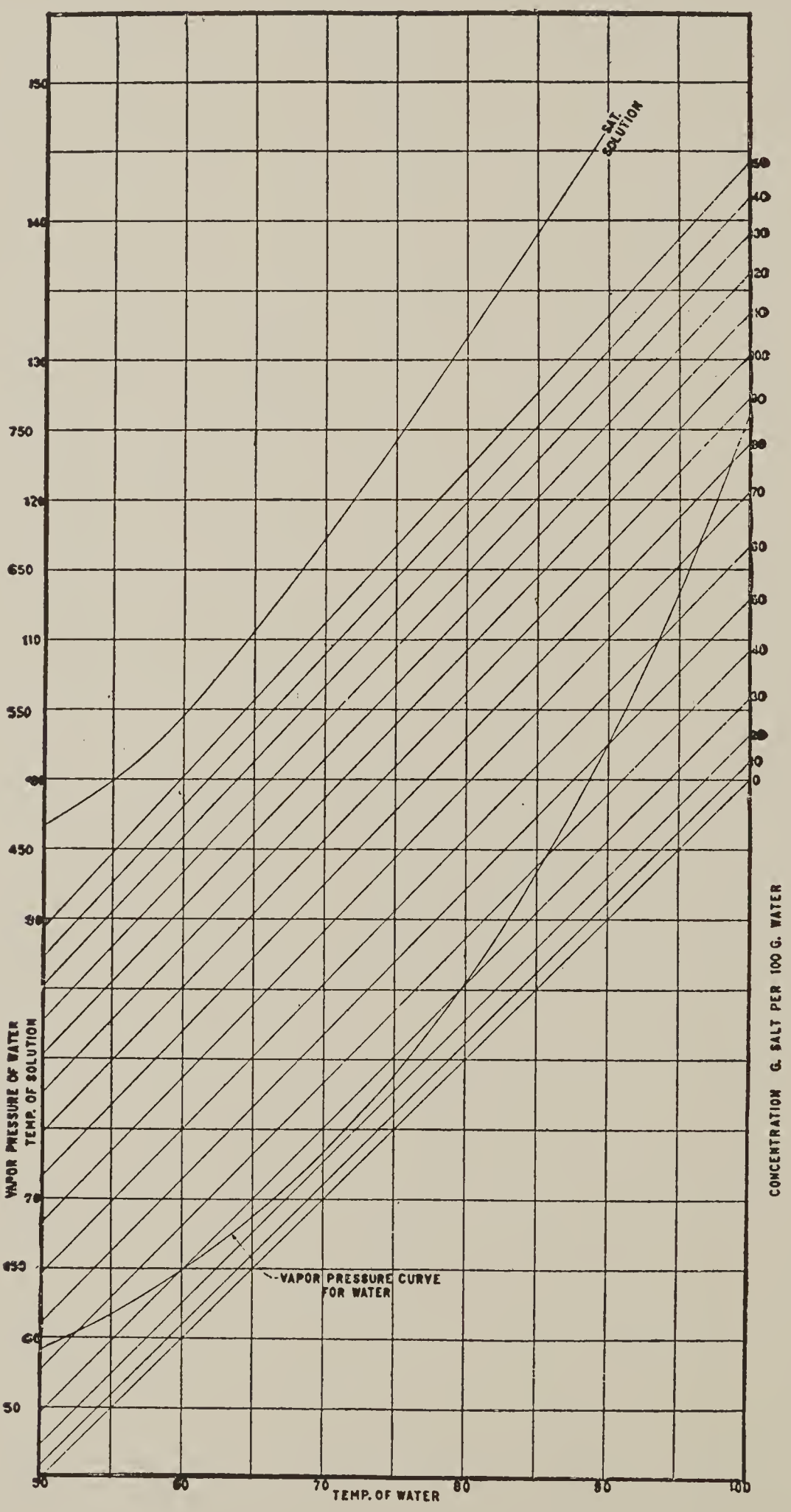

FIG. 3. Boiling points of calcium chloride solutions plotted against corresponding boiling points of water under the same pressure.

Solving Some Evaporator Problems

As a second simple illustration of the use of Fig. 3, assume that a calcium chloride solution is being concentrated in a single effect evaporator. Exhaust steam is available at a pressure corresponding to 105 deg. C. The minimum permissible temperature

TABLE IV

Vapor Pressure of $CaCl_2$ Solutions at Various Temperatures. Values from Fig. 3.

Temperature of Solutions Containing *G* Grams $CaCl_2$ per 100 G. H_2O

Vapor Pressure of Solution at temperature *T*	*G* = 0	*G* = 10	*G* = 20	*G* = 30	*G* = 40	*G* = 50	*G* = 60	*G* = 70	*G* = 80	*G* = 90	*G* = 100	*G* = 110	*G* = 120	*G* = 130	*G* = 140	*G* = 150	Saturated Solution
760	100 00	101 30	103.20	105.85	109.25	112 90	116.70	120.60	124.00	127.25	130.35	133.35	136.20	139.05	141.65	144 20	179.5
720	98.50	99 80	101.70	104 32	107.70	111.35	115.12	119.00	122.42	125.69	128.75	131.74	134 60	137 40	140 00	142.51	168.0
680	96.90	98.15	100.05	102.70	106.05	109 70	113.45	117.32	120.75	124.00	127.05	130.00	132.89	135 70	138.29	140.75	162.1
640	95.30	96.50	98.40	101.00	104 38	108 00	111.75	115.60	119.02	122.28	125.35	128.28	131.12	133.92	136.50	138.95	156.6
600	93.50	94.80	96.65	99.25	102.60	106.20	110.00	113.80	117.20	120.50	123.55	126.45	129 30	132.10	134 60	137.10	152.8
560	91.70	92 92	94.78	97.35	100.70	104.30	108.10	111.85	115.30	118.50	121.60	124 50	127 30	130.05	132 60	135.05	149.8
520	89.70	90.98	92.80	95.35	98.70	102.30	106.00	109.82	113.25	116.45	119.52	122.45	125 20	128.00	130.48	132.99	146.3
480	87.60	88 82	90.63	93.20	96.55	100.10	103.80	107.60	111.00	114.20	117.28	120.20	122 95	125.70	128.18	130.60	143.0
440	85.40	86.60	88.40	90.90	94.20	97.75	101.50	105.25	108.65	111.88	114.90	117.80	120.55	123.30	125.75	128.10	139.5
400	83 00	84.15	85.90	88.45	91.70	95.25	98.95	102.75	106.10	109 30	112.35	115.25	117.95	120.65	123.10	125.45	136.0
360	80.30	81.50	83.25	85.75	89.00	92.55	96.20	100.00	103.40	106.55	109.60	112.45	115.15	117.85	120.25	122.60	132.0
320	77.50	78.55	80.30	82.75	86.05	89.55	93.20	96.95	100.35	103.50	106.50	109.35	112.05	114.70	116.10	119.40	127.9
300	75.92	76.95	78.68	81.15	84.40	87.90	91.50	95.30	98.65	101.85	104.85	107.70	110.35	113.00	115.35	117.65	125.6
280	74.35	75.40	77.10	79.55	82.80	86.25	89.90	93.65	97.00	100.20	103.20	106.00	108.65	113 30	113.60	115.90	123.2
260	72.55	73.60	75.28	77.70	81.00	84.40	88.00	91.80	95.10	98.30	101.30	104.10	106.75	109.40	111.65	113.90	120.6
240	70.60	71.70	73.35	75.75	79.00	82.43	86.00	89.80	93.10	96.30	99.30	102.10	104.70	107.30	109.60	111.85	118.1
220	68.60	69.65	71.30	73.70	76.90	80.35	83.95	87.70	91.00	94 20	97.20	100.00	102.60	105.20	107.45	109.65	115.5
200	66.55	67.55	69.20	71.60	74.75	78.15	81.75	85.50	88.80	92.00	95.00	97.75	100.35	102.90	105.15	107.35	112.5
180	64.15	65.15	66.75	69.10	72.30	75.70	79.30	83.00	86.30	89.45	92.40	95.20	97.80	100.35	102.50	104.70	109.5
160	61.60	62.55	64.15	66.50	69.70	73.05	76.65	80.30	83.65	86.75	89.70	92.45	95.05	97.55	99.75	101.90	106.2
140	58.60	59.65	61.20	63.60	66.75	70.05	73.60	77.30	80.60	83.75	86.70	89.45	92.00	94.45	96.60	98.70	103.1
120	55.45	56.35	57.90	60.25	63.35	66.70	70.25	73.90	77.20	80.35	83.35	86.00	88.55	91.00	93 10	95.15	100.2
110	53.65	54.60	56.10	58.40	61.50	64.85	68.35	72.00	75.30	78.45	81.35	84.10	86.60	89 05	91.15	93.15	99.0
1	51.65	52.60	54.10	56.35	59.50	62.80	66.30	70.00	73.25	76.40	79.30	82.00	84.50	86.95	89.00	91.00	97.6

drop across the heating surface to give the desired evaporator capacity is 20 deg. C. The evaporator is operated at an absolute pressure of 160 mm. What is the maximum degree to which the concentration of the $CaCl_2$ solution can be carried, and satisfy the above conditions?

From the ordinate of 160 mm. pressure, extend across horizontally to the vapor pressure curve for water, finding that water would boil under this pressure at 61.6 deg. C. Then extending up vertically on this abscissa (61.6 deg. C.) to the ordinate 85 deg. C., the concentration of the solution that would boil at 85 deg. C. under 160 mm. pressure is found by interpolation to be 85.2 g. $CaCl_2$ per 100 g. of H_2O. This is the concentration sought. The actual temperature drop is 105 deg. — 85 deg. = 20 deg. C., while the temperature drop for evaporating water under the given pressures would be 105 deg. — 61.6 deg. = 43.4 deg. C.

Or again, suppose it were desired to carry the concentration to 150 g. of $CaCl_2$ per 100 g. of water, in the above case, what

would be the necessary temperature of the steam to have a minimum effective temperature drop of 20 deg. C. across the heating surface when the solution reached this concentration? The absolute pressure in the evaporator is 160 mm. Extending across horizontally from this pressure ordinate to the vapor pressure curve for water, it is found that water will boil at 61.6 deg. C. under this pressure. Extending up vertically from this abscissa of 61.6 deg. C. to the curve for a solution of 150 g. of $CaCl_2$ per 100 g. of water, it is found that this solution would boil under this pressure at 101.9 deg. C. Then to give an effective temperature drop of 20 deg. C., the temperature of the steam would have to be 101.9 deg. + 20 deg. = 121.9 deg. C., or 1580.8 mm. absolute pressure; whereas for evaporating water under like conditions, the steam would have to be under an absolute pressure of only 378.8 mm.

A bibliography of references on the vapor pressure of calcium chloride solutions is appended.

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HISTORY AND DEVELOPMENT OF THE GLUE INDUSTRY AND GREASE EXTRACTION IN AMERICA

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The art of making animal glue and its use in veneering was known to the Egyptians at as early a time as during the reign of the third *Thothmes,* supposedly the Pharaoh of the Exodus. In the sculptures of Thebes there is represented a workman who has joined a piece of rare red wood to a yellow plank of sycamore. In order to show that the yellow wood is of inferior quality, his adze is shown carelessly fixed in a block of the same wood according to its color. At his side are some of his tools, with a box or small chest, made of inlaid and veneered wood of various hues, while two other men are seen in the same part of the shop, one of whom is grinding something with a stone on a slab while the other is apparently spreading glue with a brush. The appearance of a pot on the fire and a piece of glue with its characteristic concave fracture before the workman joining the two pieces of wood, practically attest the use of glue by the Egyptians over 3000 years ago.

Gaius Plinius Secundus better known as Pliny the Elder and author of the *Naturalis Historia* knew the value of a good glue, for he writes:

> "Great cunning there is in making strong glew,
> And in the feat of joining with it too."

Evidence also exists that during the flourishing days of the *Roman Empire* the manufacture of glue formed one of the industrial pursuits of the Romans, while centuries later, in the *Elizabethan age,* glue was also known as a valuable and useful product. *Shakespeare* spoke in eloquent testimony of the adhesive virtues of glue when said in *Titus Andronicus,* Act II, scene 1:

"Go to; have your lath glued within your sheath,
"Till you know better how to handle it." (*Lambert,* Glue and Allied Products, London, 1905.)

These speculative statements are, of course, interesting only from a historic point of view, because the glue industry, as we know it, is of a much later date and its progress to the dominating power it now assumes is in fact due and to a great extent interdependent upon the various inventions in processes and apparatus of the chemical and allied industries in general.

Several of the earlier chemists like *Fougeroux*, *Bayen,* and *Charlard* record the observation that bone, immersed in acid, loses its inorganic substance, while the residue which remained possessed the properties of a jelly.

But glue was made to a greater extent after the establishment of the first sulphuric acid plants erected in England; in the year 1746 by *Dr. Roebuck;* in 1766 in France at Rouen and in 1820 at Potschappel near Dresden. Glue must have been an expensive product then, with sulphuric acid selling at $238.00 per ton at that time.

Hérissant proved in 1758 that bones, when treated with dilute acids, yielded the animal substance of the bone which retained the original structure and was easily convertible into glue. These experiments made by Hérissant were splendidly confirmed by the investigations of *Hatchett,* the English chemist, in 1806.

Papin recommended the jelly prepared by the acid treatment of bones in his digester, as an article for human food, which, of course, was somewhat erroneous.

LeBlanc's invention now marks another stepping stone in the glue industry. By his epoch-making invention of the production of soda from sea salt with sulphuric acid, whereby enormous quantities of hydrochloric acid were liberated, which only with difficulty could be condensed, these earlier chemists quite naturally tried to find a use for these gases, which, in the way they were allowed to escape, constituted a nuisance. So they proposed the leaching of bones with these acid gases and this may also account for the fact that we find the original continental glue plants usually attached to the LeBlanc Soda factories.

The proposal of LeBlanc was followed in 1793 by *J. F. Boby*, Paris, who patented a process of leaching bones with hydrochloric acid. An improvement of this is shown in the patent issued to *Darcet* (1817). Closely following came the patent to *Dupasquier Senior and Junior*, 1818, who already claim the production of a bone glue, capable of replacing isinglass.

These older chemists must have found that quite a large volume of hydrochloric acid was necessary to leach bones, so in 1822, *N. Pascal,* of Marseilles, patented the alternate use of hydrochloric and sulphuric acid and claimed to be able to save twenty-five per cent of the hydrochloric acid. This attempt to save on acid we find represented to an equal extent in the patent to *Bergmann* seventy-five years thereafter.

The glue jelly which was produced has of course to be cut in smaller slabs in order to facilitate drying. The drying was done in the open air and later—owing to the inclemencies of the weather—in ventilated lofts. The slabs were simply cut by a knife. This method must have proved very cumbersome to the ancient gluemaker and we find therefore efforts to do this work by a machine which culminated in 1823 in the patent to *Devoulx,* of Marseilles, for a glue-cutting machine.

Maclagen, of Dunkerque, took out a patent in 1824 for a special apparatus for the production of glue and gelatine.

By now there had also accumulated a large quantity of calcium chloride — a by-product of the LeBlanc Soda plants — and we find in 1827 a patent taken by *B. Sian, Gauloffret* and *Boffe* proposing the use of calcium chloride in treating bones and glue. This would thereafter mark the first step in the production of liquid glue.

Nearly one hundred years thereafter we find a patent issued to *Alexander* for the same pupose.

Up to that time glue was made — as we now call it — straight, from one kind of material exclusively.

Loval, Paris, protected a process for making hide glue (1832) by mixing 16 parts of white trimmings with 11 parts of shavings, claiming a better quality of product and utilizing another by-product not used at that time. This process opened the field for mixed glues and corresponds very closely to the present day practice of making chromeglue by mixing an aliquote part of shavings to the pieces.

In 1836 we find *Beaujean* and *André* applying HCl in a strength of 6 degrees Baumé to the bones of sea animals such as whale, shark, dolphin and seal. In 1918 we find our Japanese brethren proceeding along these identical lines.

Capdeville, of Paris, suggested and patented the process of drying glue in vacuum (1838).

For the washing of gluestock *Briers Senior* adopted and patented the use of the *Paper-Hollander* (1840).

While up to this time the gluestock had been treated in the form as obtained from the tanners, *Swinbonne* (1841), seeing in all likelihood the success of *Loval,* protected a process for dehairing and comminuting the material preparatory to treatment and cooking.

In 1842 we find *Herm. Paulsen,* of New York, obtaining a patent for cooking bones under pressure.

W. Ruthay was the first to patent the use of SO_2 to bleach gluestock before washing, while *Dorday* protected a process using chloride of lime and hydrochloric acid for the preparation of his material.

The drying methods — even as then practised in ventilated lofts —were awkward and dependent upon weather conditions, so in 1847 *McDougall* tried to overcome this drawback to the then used process, by exposing the glue slabs to a current of air blown over concentrated sulphuric acid or calcium chloride. A later attempt along the same line is shown in the patent to *Schimmel* (1910),

Ebenezer Rowe, of Rockport, Mass., patented a cooled roller for the purpose of chilling isinglass (1848) which is the forerunner of the modern glue-chilling machines.

O. Rich (*Le Technologiste,* 1856, 378) was the first to make glue from tanned leather scraps.

J. Stenhouse (*Ann. Chem.* & *Pharm.,* 104, 239) reports a process of making hide glue in a Papin digester, together with analytical data. The purification of glue by means of vinegar to form gelatine is due to *C. Puscher* (*Polytechn. Journ.,* 183, 474).

In 1853 *David D. James,* of Cincinnati, patented the application of steam coils in open vats, for cooking.

The concentration of thin glue liquors in a specially constructed pan is described by *E. Tucker* (*The Pract. Mechanic. Journ.,* 1857, 125).

Chas. W. Cooper, of Brooklyn, suggested in 1861 the use of CO_2 to convert soluble limesalts into their insoluble form.

Either because the dried glue was unsightly or in order to save space in shipping, the first gluecrusher was invented by *Emerson Goddard,* New York (1864).

Robert Jackman, New York, introduced in the same year the water bath.

The glue kettle residue, which yields a fertilizer, also contains grease. *C. W. Cooper,* probably looking for more revenue, suggested obtaining therefrom the grease by decomposition with sulphuric acid (1865).

Rowe's suggestion of drying glue finds another echo in the process patented by *George Guenther* to dry glue upon rotary surfaces. This proved unsuccessful, so he applied the rotating surface to the chilling of glue liquor (1867).

William Adamson in the same year patented the method of drying glue by aeration, while we are indebted to *George Upton* for a cooking tank with perforated false bottom and circulating chimney, which even at the present time is still in actual use.

Glue was clarified up to this time simply by settling. As this operation took too long time *John Michael Fuchs* introduced in 1867 the "filterbox," which was followed by the *Aspden* filter in 1889 and following the failure of the filter-press gave rise to the adaptation of the paper-pulp or asbestos-pulp filters so successfully used in the brewing industry and which found their expression in the constructions of *Karl Kiefer, Union, International, Philippe* and others.

While the Frenchman Capdeville had already suggested drying in vacuum in 1838 it remained for *George Guenther,* of Chicago, to actually do it in 1869.

Glue, after concentration and cutting into slabs, was laid upon cotton fishnets to dry. During the process of drying these slabs adhered too strongly ("stuck") to the cotton fiber, so *William Adamson* suggested (1868) the coating of these nets with paraffin to prevent the glue from "sticking." While, in the manufacture of gelatine, cotton nets are still in use, in the glue industry proper the cotton nets have been entirely replaced by heavily galvanized iron wire nettings.

To better the grade of glue, *David K. Tuttle* and *Orazio Lugo* proposed in 1869 to first degrease the material by means of a benzin hydrocarbon.

In 1870 we find efforts to supplant hand labor — an expensive method of laying glue jelly upon nets — taking another impetus by the invention of a spreading machine by *Andrew Dietz.*

The results obtained in the paper industry must account again for the introduction of SO_2 and sulphites into the glue industry by *B. F. Shaw,* of Cambridge, Mass.

1871 brings us to the process of preparing stock for the manufacture of gelatine by treating bones with SO_2 or H_3PO_4.

The efforts of *McDougall* (1847) find an echo in *Oscar S. Follet's* introduction of $CaCl_2$ for the purpose of drying glue (1873). In the same year *Wm. Plumer* proposed to dry glue in airtight chambers by means of blowers.

An improved method of cutting glue jelly is introduced in 1875 by *Hennel Stevens,* in the form of a heated platinum wire.

Following the suggestion of Shaw, *Chas. O. Garrison* applied the use of H_3PO_4 to the treatment of hornpith (1875).

The extraction of fat and grease by means of volatile solvents—already suggested by Tuttle and Lugo—finds another advocate in *Deiss.* To avoid the loss of glue-yielding substances, which is unavoidable in steaming bones for the purpose of removing the grease, even if the steaming process is only continued for a short time and furthermore, in order to better the quality of the glue, Deiss experimented in 1868 with carbon disulphide. But as the glue produced was bad, and the fat obtained had such a disagreeable odor as to render it almost worthless, his experiments were discontinued. *Voll* suggested in 1871 Canadol (gasolin) as solvent, whereupon in the same year *M. Terne* patented the use of petroleum benzin in the United States. But it remained for *William Adamson* of Philadelphia and *Friedrich Seltsam* of Forchheim, Germany, to solve this problem. Adamson and Seltsam—both prominent gluemakers in their respective countries—experimented along the same lines at about the same time (1878). Based upon their experience, *Wm. Adamson* obtained his U. S. Patent in 1879 while *Seltsam's process* was in successful operation in 1880. Seltsam also realized that the extraction of grease would be more complete and perfect if the bones were in comminuted form—which *Swinbonne* already had suggested for hides—so, he introduced in the same year his bone-crusher. The Adamson and Seltsam patents therefore constitute the basis upon which all our modern extraction apparatus are founded. While the Adamson process worked by percolation, *Seltsam's* process operated under pressure and distillation. The great importance of the extraction process—which is now used not only in the glue industry but in a great many others for the extraction of oils and fats from seeds, paraffin, rubber and waxes, etc., warrants an explanation of the many types of apparatus in use.

The great multitude of extraction apparatus can be classified as follows:

(*a*) Stationary extractors;
(*b*) Rotary extractors—
With or without interior heating coils,
With or without steam jacket,
With or without built-in still,
With or withou agitators,
With or without false bottoms,
With sidewise, or with bottom discharge,

and the operations may be classified as follows:

By trickling or percolating with cold or with warm solvent,
By flooding material with cold or with warm solvent,
From the top downwards,
From the bottom upwards,
By solvent distillation,
By simultaneous steam distillation,
Under pressure,
Under vacuum,
Under atmospheric pressure,
Continuous, single, double, or in series,
Intermittent, single, double, or in series,
Solvent inlet by gravity, by pumping or vacuum.
The condensers may be:
(*a*) Vertical,
(*b*) Horizontal,

single, double, parallel or in series.

(1) Solvent in pipes surrounded by water,
(2) Water in pipes surrounded by solvent.

Within this classification every existing extraction apparatus may be placed. While it is impossible to enter upon the merits of the different types of apparatus it might be stated that in the selection of the proper apparatus the following points are a good guide:

(*a*) First cost,
(*b*) Running expenses.
(1) Steam, (2) water, (3) solvent in circulation, (4) solvent loss, (5) labor.
(*c*) Space required,

(*d*) Maintenance and fixed charges.

Thomas P. Milligan introduced in 1881 alum to harden the tissue, after dehairing and liming.

In 1886 *W. Upham* patented the process of drying glue upon a moving apron, while *Le Page* protected in the same year the process of deodorizing fish glue by means of borax.

The improved glue cutter of *Jarves,* Detroit, appeared in 1887 which found corresponding expression in the designs of *Schirm, Schneider, Friedrich, Fels* and *Ruf* and others.

The *Weldon process* of manufacture of chlorine is responsible for the introduction of chlorine in the glue industry by treating bones simultaneously with MnO_2 and H_2SO_4, by *J. R. Pringle* for the purpose of bleaching the stock.

The *Adamson* washing machine sees an improvement in construction of *C. W. Cooper* in 1889 after *Hoeveler, Brooks* and *Meyer* had made very good suggestions.

Following the success attached to the extraction of bones by volatile solvents, *F. J. Machalske* proposed the extraction of garbage by the same process.

The Jarves glue cutter of 1887 was improved by the introduction of a removable head and knives (1895). In the same year *J. E. Kunitz* proposes to bleach glue in the drying tunnels by developing SO_2 therein.

The first process to make glue in the cold by means of alkali is represented in the patent of *E. Mills,* of Glasgow. In the meantime the handling of glue became better understood and found its expression in the glue dissolver of *Friman Kahrs,* 1897.

The Goddard glue crusher finds an improvement in the *Wurmbach* disintegrator, 1898.

The success attained by other industries with *Ice or Refrigeration* machinery gives rise to the introduction of such apparatus in the glue plants.

To utilize glue and glycerin from waste printers' ink rollers for the purpose of producing alcohol primarily is the object of a patent to *J. Takamini,* who is closely followed by *Jobbins* in 1900.

With the production of carbon tetrachloride by *Griesheim* in 1900 we find among the earlier advocates for the use of this solvent *Goehrig* and *Bruecke.* In spite of the great advantages of CCl_4 as a solvent — it being heavier than water and practically non-

inflammable — it has found but sporadic introduction, owing to the high cost of the solvent and the higher cost of the special extraction apparatus necessary.

The sulphite cellulose industry — as previously stated — contributed the SO_2 process which found its best expression in the process patents of *Max Schroeder* in 1894, followed very intelligently by *Arens* and further by *Hilbert, Hewitt* and *Bergmann.*

Clarification of glue liquors by means of albumin or casein was made the object of a patent by *P. C. Hewitt* (1894). The paper hollander, introduced by Briers in 1840, finds a revival by *E. R. Hewitt* in 1895.

By this time the sugar industry had already contributed the diffusion battery and the vacuum evaporator in the *Yaryan* and *Swenson* types to the glue industry.

Kostálek introduced a filter with horizontally arranged sieves (1902). The same year sees the introduction of vacuum drying machinery in the form of *Passburg's* Drum Dryer. This process eliminates the chilling, spreading, and drying operations entirely together with grinding and while this process is in very successful operation in several continental glue works it has not as yet been introduced into American glue plants.

In 1903 the Scotchman *McCormack* patented a process for making glue in a centrifuge. This year also brought the *Kestner* evaporator into the glue industry.

Chrome-tanning already suggested by *Knapp* in 1858 has been perfected and due to the appearance of chrome leather offal we see now this material entering the glue works in large quantities (1902). The original patent of *H. Weiss* gave this process a great impetus.

An improved form of hidestock glue cutter is introduced by *Burberg, Taylor-Stiles* and others.

The comminuting of bones suggested by *Seltsam,* in 1881, finds another advocate in *Hilbert* (1904) who goes one step further by grinding the bones to flour preparatory to making glue. While good, this process has not survived. *Schneider* follows Hilbert with a different apparatus.

Stiegelmann and *Dehnel* (Badische Co.) contribute a new bleaching agent for glue in the form of basic zinc formaldehyde.

While hydrogen peroxide had been used by this time in bleach-

ing of glue and specially gelatin liquors, *Thiele* suggested and used (1908) alkali peroxides successfully in the preparation of casein and was followed by later advocates, *Fuhrmann* and *Bunzel* (1912).

Liquid glue, already known since 1827, finds another impetus in the introduction of naphthalene sulfonate by *Frederik Sulf* in 1910. *Halloran* again suggests hypochlorites in treating leather. In 1911 appears *Thiele's* cooking tank and process, whereby glue or gelatine is removed as quickly as formed in continuous operation.

Grosvenor proposes in 1914 the drying of glue by means of a

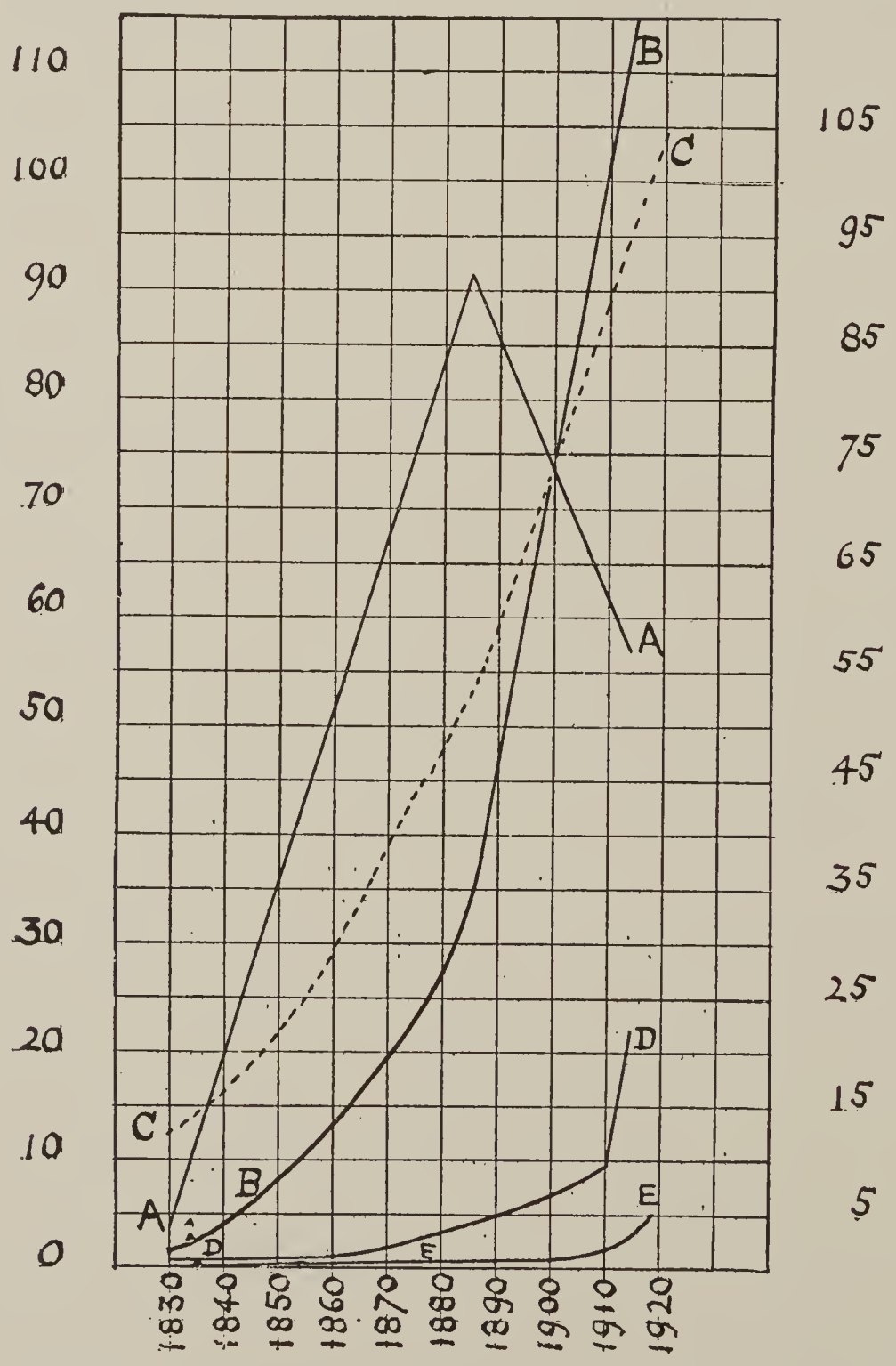

FIG. 1.

current of purified air. This year also marks the introduction of the *super-centrifuge* for the purpose of clarifying liquors.

Of the special forms in which glue enters into the market we

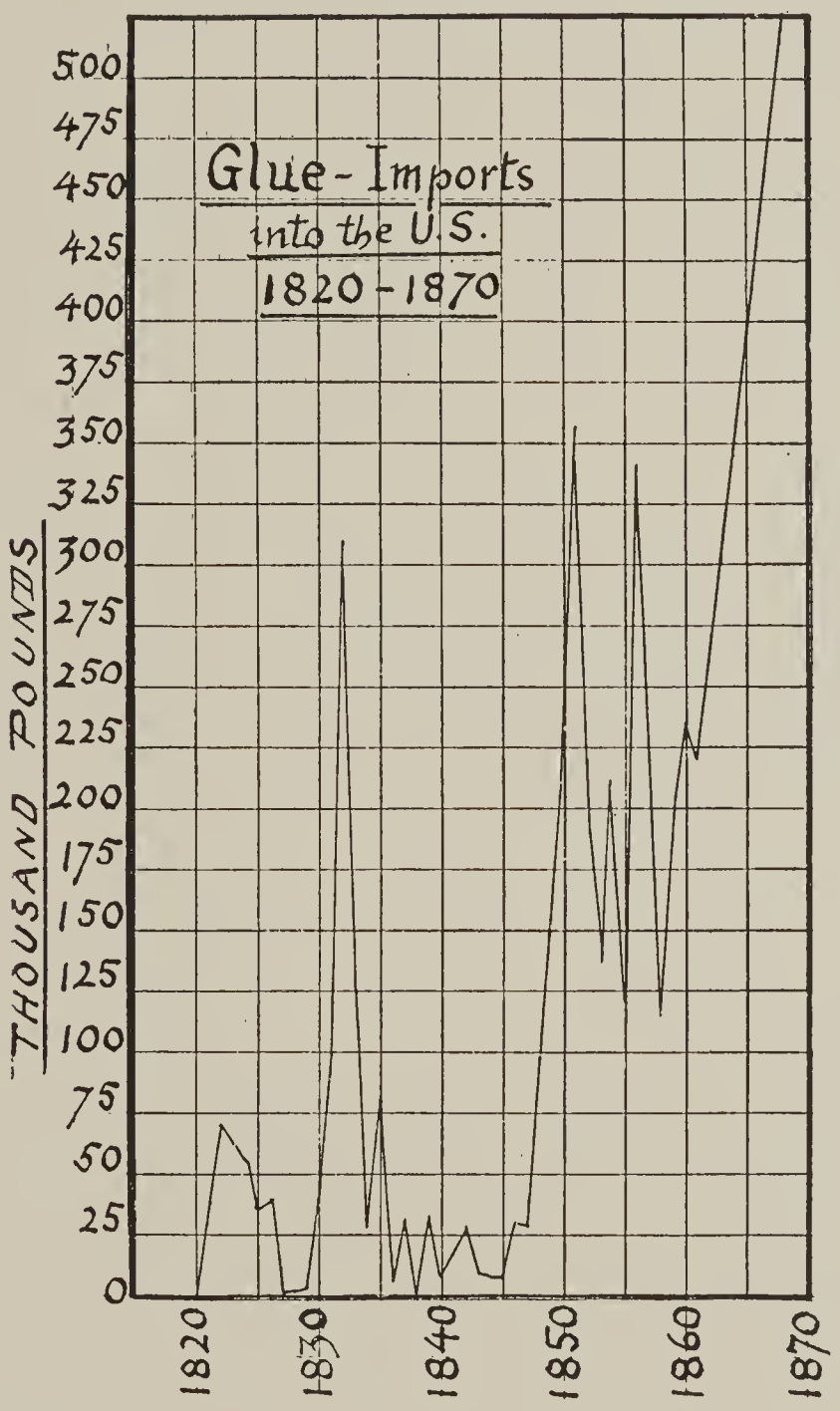

FIG. 2.

have to record glue and gelatine pearls, introduced by the *Scheidemandel Co.* in 1915. This form is produced by allowing a 25–50 per cent gelatine solution to drip into a mixture of CCl_4 and benzin cooled to 10° C. This process finds an echo in the patent of *Salm* shortly thereafter.

The year 1916 marks the introduction of the electric current for the purpose of making and bleaching glue and gelatine as expressed in the patents of *Schwerin* and *Electro-Osmose*.

In 1918 we hear for the first time from far-away Japan. *Teikoku Kwagaku Kogyo-Kabushikikwaisha* proposes to make gelatine from the flesh and brains of the sperm whale, while *D. Kobayashi* patents a process of making glue by immersing bones in a 5–10 per cent solution of acid phosphate.

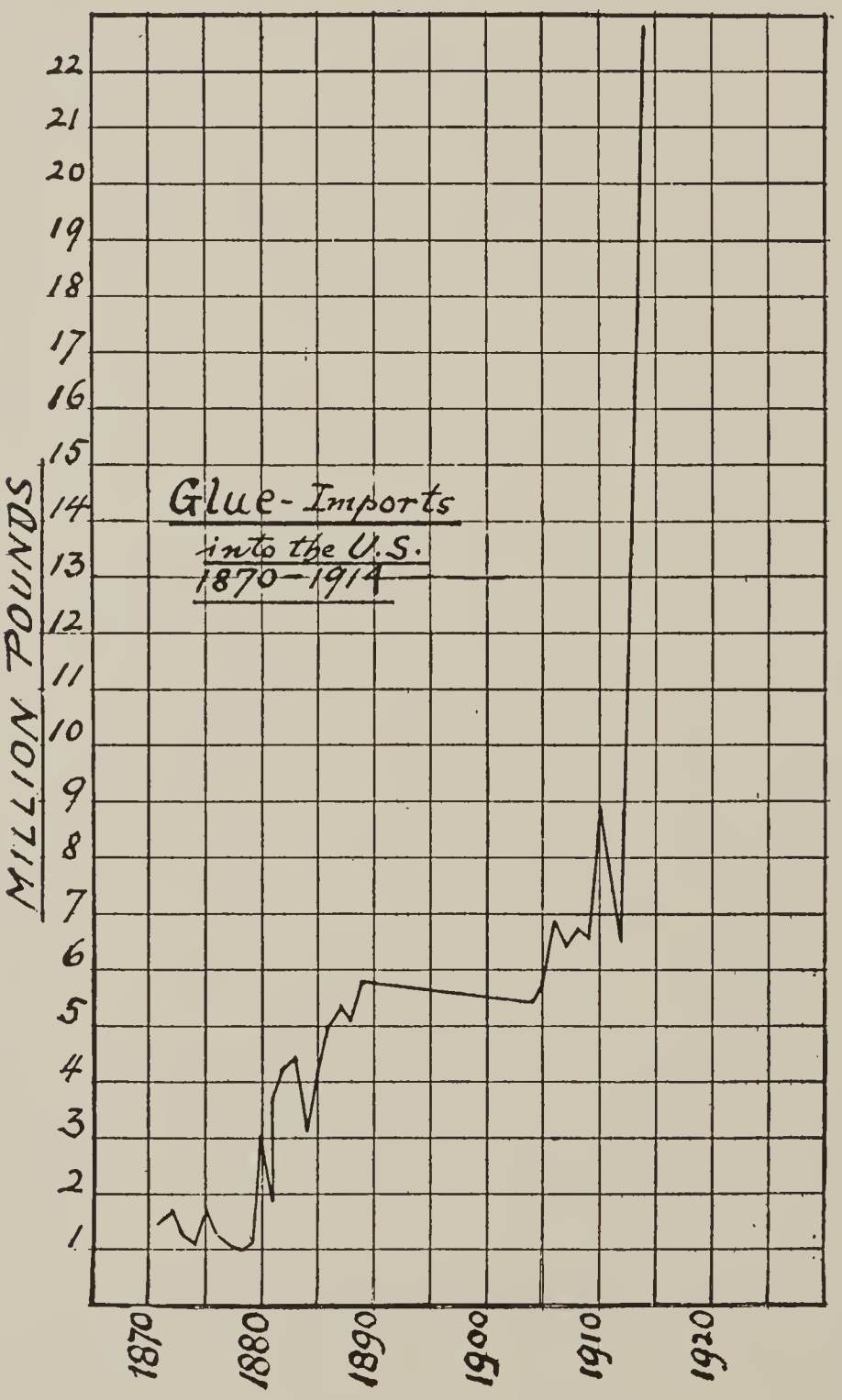

FIG. 3.

Finally we have to record the ever increasing methods of purification of water and effluvia.

Thus it is seen that many men of many countries have con-

tributed to the knowledge and processes of manufacture, while a great many industries have furnished or supplied the basic prin-

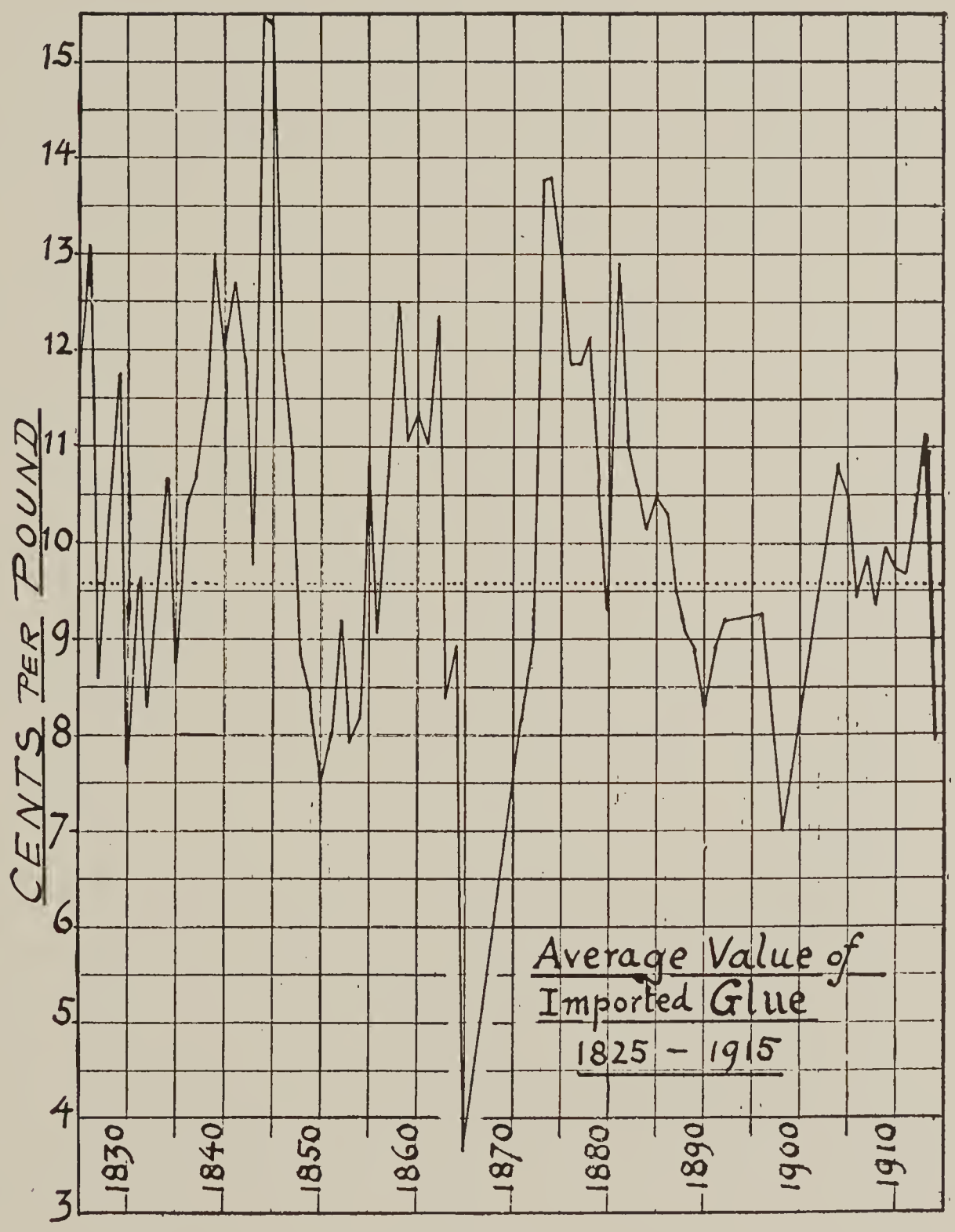

FIG. 4.

ciple for different types of apparatus — now considered a necessity in the manufacture of glue — chief among which are the acid, alkali, tanning, textile, paper, cellulose, brewing, fertilizer, sugar, coaltar, and fine chemical industries.

The adaptation of mechanical devices now so extensively used and responsible for the success of the glue industry in the form

of conveyors, elevators, rail systems, cranes, blowers, exhausters, mills with wind separation, gyrator sifters, and rotary dryers is in most cases due to the success which these apparatus had in other industries.

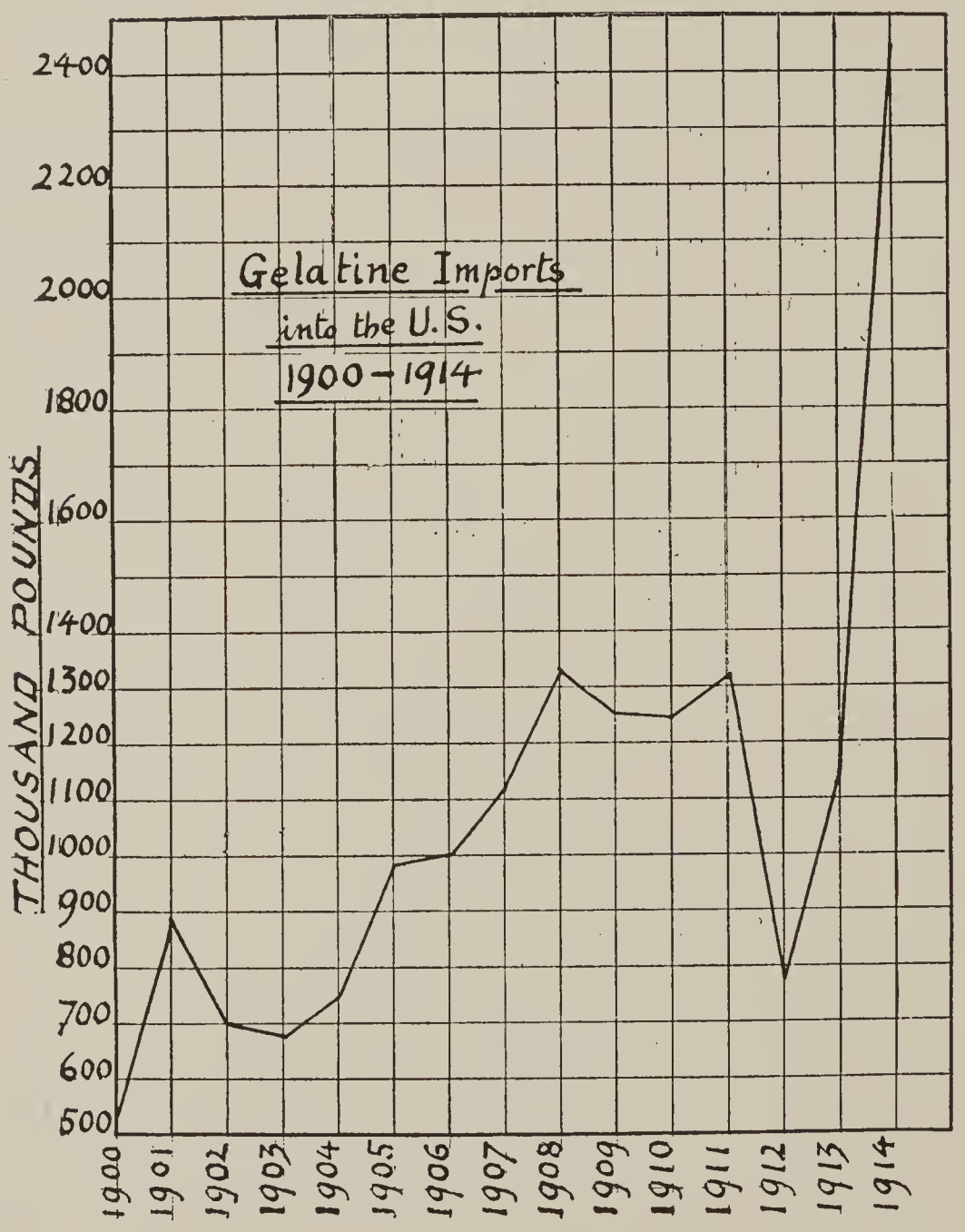

FIG. 5.

The glue industry, having grown largely by the application of the experience of others, has nevertheless shown a great deal of impetus of its own and, in turn, has contributed several of the best methods and apparatus which are utilized by other branches of industry to their great benefit.

I shall now append a classified list of patent records, together with literature addenda in the sequence of manufacturing subdi-

visions, which, while perhaps not as complete as desired, will nevertheless show the progress made in the glue industry and may serve as the basis for future expansion.

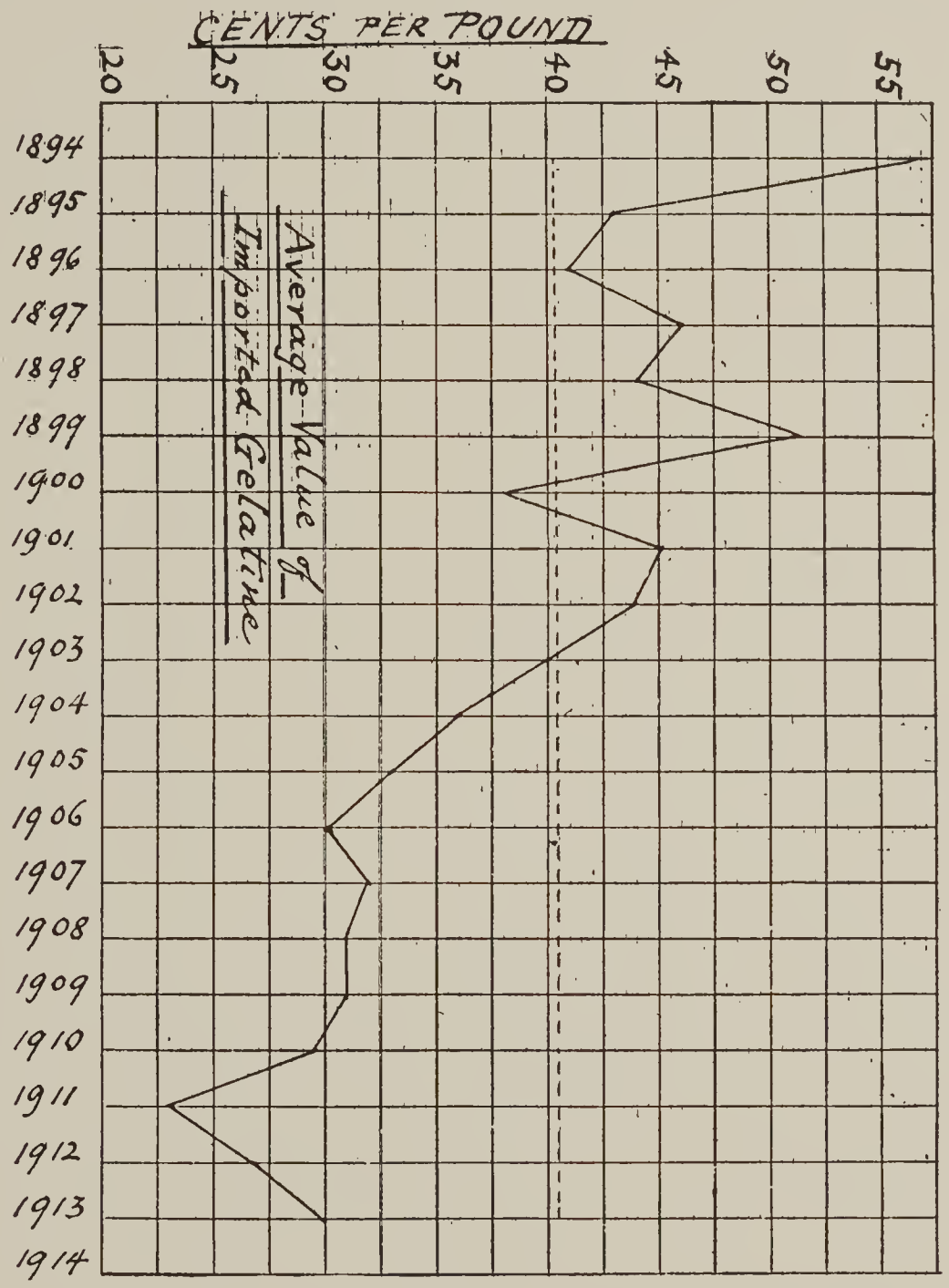

FIG. 6.

The accompanying chart, Fig, 1, illustrates consistently the development of the Glue Industry in the United States and represents in:

Curve *A–A* The number of establishments,
" *B–B* Production of all glue in million lbs.,
" *C–C* Population of the United States in millions,
" *D–D* Imports of glue into the United States (million lbs.),
" *E–E* Exports of glue from the United States (million lbs.).

Table I interprets the curve *A–A* by statistical data relative to the growth of the industry as to number of workmen, *HP*, and capital employed as well as the amount of money expended for raw material in an average glue factory in the respective years.

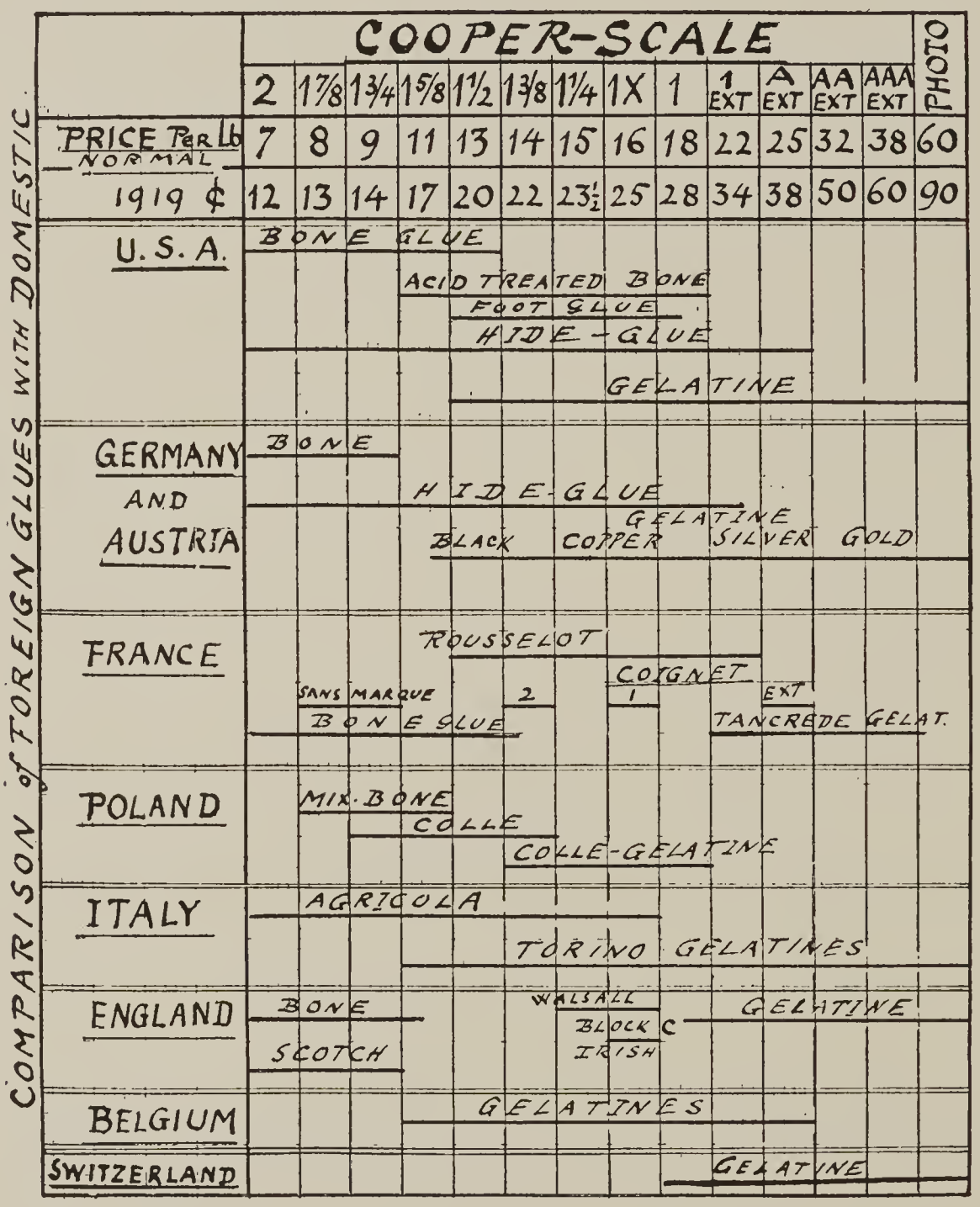

FIG. 7.

Table II illustrates the increase in imports of glue and gelatine into the United States, as well as the exports of glue from the United States together with the respective money-value.

We see by Chart 1 that at the end of the year 1830 or prior thereto, there were just 4 glue factories in the country, whose production was small as seen by the imports for that year. The

high mark as to number of establishments was reached in the decade 1880–1890 when the country possessed 92 establishments making glue. As sudden as curve *A–A* went upwards it commences and continues a downward course, so that we find in 1914 only 57 glue factories engaged in the business. With the decrease in the number of establishments, we find the production continually on the increase, causing a considerably higher production for the average plant. Contemplating this curve further we see an indication as to the future course of the industry.

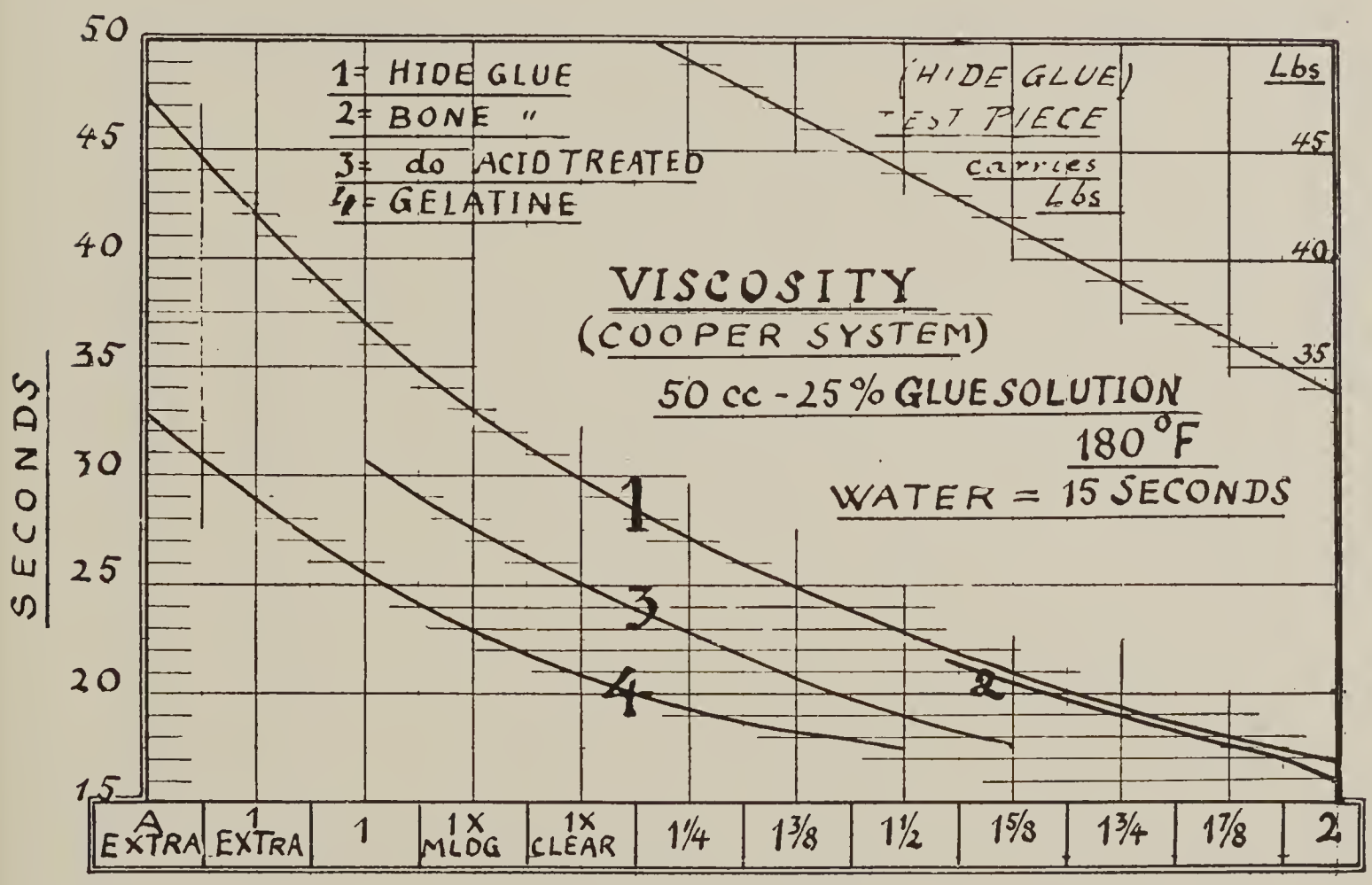

FIG. 8.

The imports of glue rose from 40,344 lbs. in 1830 to 22,714,877 lbs. in 1914. This heavy increase in imports particularly in 1914 must be charged to "dumping" just prior to the War.

Despite the superiority of American-made glues in comparison to European grades the exports of American glue have not kept pace with the production or the imports. In 1830 the export figures show 206 lbs. while in 1914 export figures are given as 2,351,770 lbs. At the end of the War in 1918 the United States exported close to 5 million pounds, or doubled since 1914.

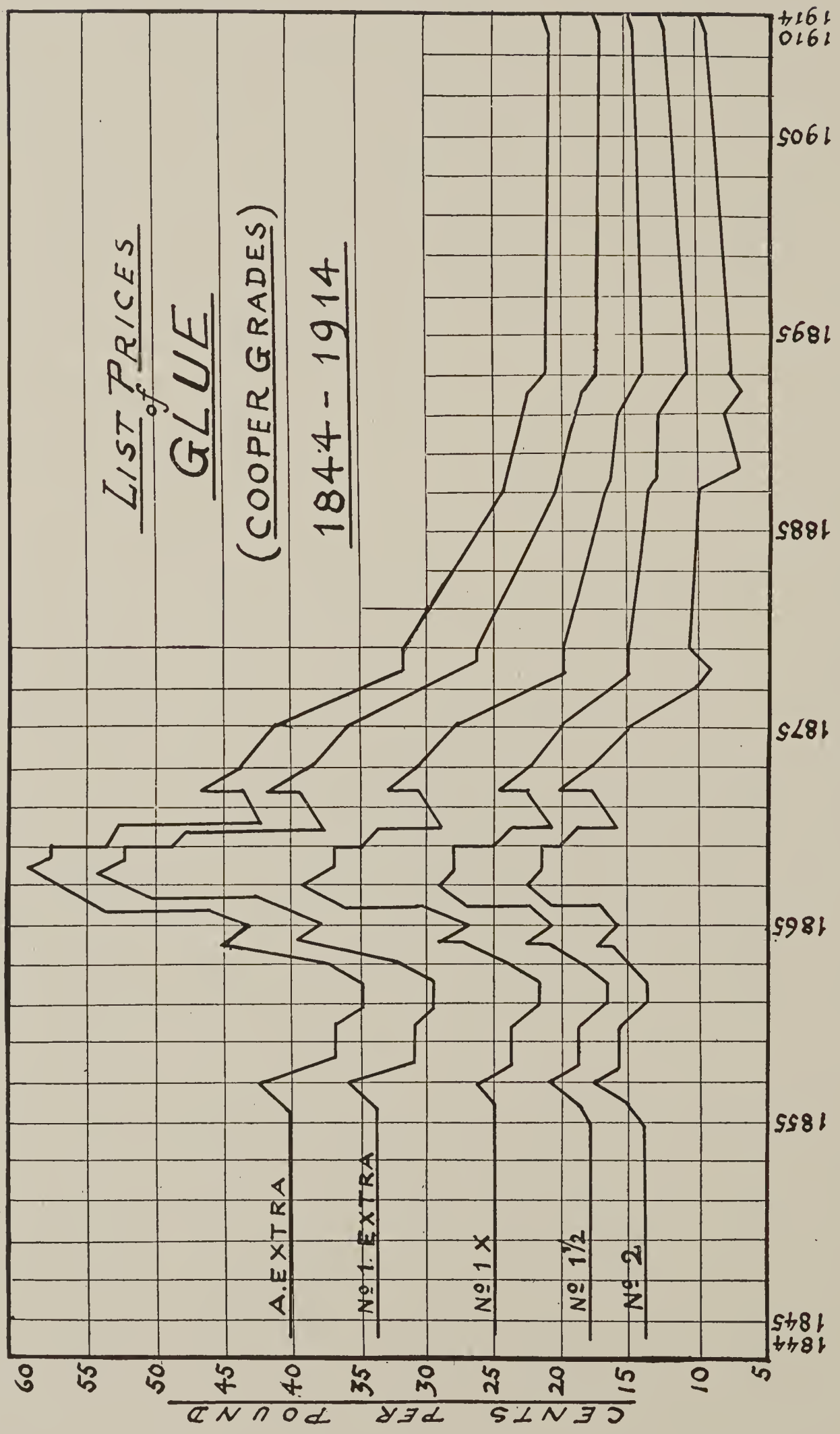
LIST of PRICES
GLUE
(COOPER GRADES)
1844 - 1914
CENTS PER POUND
60
55
50
45
40
35
30
25
20
15
10
5
A. EXTRA
No 1. EXTRA
No 1 X
No 1½
No 2.
1844
1845
1855
1865
1875
1885
1895
1905
1910
1914

FIG. 9.

As the production of the European countries is at present not more than 50 per cent (at the maximum) of their normal production it may be consistently expected that the American glues will experience a further increase in exports as their quality will — no doubt — conquer a much larger field and obtain that recognition abroad which their quality justly deserves.

TABLE I

	Number of Establishments	The Average Glue Factory Employed:			
		Workmen	HP	Capital $	Raw material $
1830.....	4	.	.	.....	....
1850.....	47	8	.	11,000	5,800
1870.....	70	13	15	28,000	12,600
1890.....	82	22	60	48,000	34,000
1914.....	57	66	234	300,000	151,500

TABLE II

	Imports into U. S.				Exports from U. S.	
	Glue Lbs.	Value $	Lbs. Gelatine	Value $	Glue Lbs.	Value $
1830..	40,344	3,110	.....	.....	206	29
1850..	212,348	15,906	.....	.....	400	86
1860..	234,103	26,539	.....	.....	940	188
1870..	1,328,542	184,542	75,267	33,198	22,354	5,621
1880..	3,011,627	280,147	314,263	130,155	150,718	22,650
1890..	5,776,956	478,417	525,887	243,568	728,696	88,484
1900..	6,857,529	647,390	882,583	329,364	.....	.....
1910..	8,825,193	861,942	1,312,979	387,525	2,488,205	264,756
1914..	22,714,877	1,805,543	2,441,317	738,731	2,351,770	258,611
1918..	2,048,548	348,241	365,586	133,957	4,935,250	839,157
1919..	1,278,479	268,253	449,336	241,835	8,486,167	1,480,477
1920..	2,040,261	523,096	1,905,976	1,013,527	12,449,799	2,159,094

PATENTS

Preparation of Glue Stock

Bone-crusher

1881 Seltsam,
1889 Mann
1894 Chapman,
Roche,
Schirm
Croskill,
Krupp,
Jeffries,
Stedman
Mech. Mfg. Co.,

Leather Cutters

1889	Fischer, U. S.	414,766
1895	Hewitt,	545,288
1898	Wurmbach,	609,489
	Burberg,	
	Taylor-Stiles	

Washing Machinery

1877	Adamson, U. S.	188,088
1883	Hoeveler,	276,040
1884	Brooks,	299,515
1885	Meyer,	313,751
1889	Cooper,	400,441
	do	400,442
1895	Hewitt, E. R.,	533,296
	Hewitt, P. C.,	545,288

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Gebek, L., *J. S. Chem. Ind.,* 713.
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1907 Bergmann, *J. S. Chem. Ind.,* XXIII, 253.
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Bernard-Lomme, D. R. 229,526.
1908 Doerner, L., D. R. 218,487.
1909 Wurl, W., D. R. 266,131.
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Bellman, A. J., Brit. 25,455.
Harburger Werke, Brit. 27,014.
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Kuraishi, Jap. 31,259.
1918 Teikoku, Jap. 32,192.
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Stiepel,
1920 Thiele, L. A., U. S. pend. E.
Krouse, C. C., U. S. 1,338,307/8.

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1867 Upton, G., U. S. 60,968.
1857 Tucker, E.,
1874 Neuer, E., U. S. 149,673.
Adamson, W., U. S. 157,564.
1881 Seltsam-Hagen, U. S. 240,855.
Milligan, T., U. S. 247,573.
1883 Mathieu, J. A., U. S. 276,256.

1884 Swanton, T., U. S. 295,508.
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1890 Milligan, T. P., U. S. 420,163.
1893 Bertram, L., U. S. 501,759
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1908 Rice, E., U. S. 903,775.
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1868 Dietz, A., U. S. 79,736.
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1869 Tuttle & Luge, U. S. 89,709.
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1871 Rice, N. B., U. S. 114,602.
1872 McDougall, H. & C., U. S. 130,230.
Shaw, B. F., U. S. 133,896.
1877 Garrison, C. O., U. S. 191,132.
1881 Milligan, T. P., U. S. 246,182.
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1884 Ekmann, C. D., U. S. 307,754.
1885 Gahler & Pilz, U. S. 318,367.
Schroeder, Brit. 15,664.
1886 Milligan, T. P., U. S. 333,964.
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1894 Schroeder, M., U. S. 518,861.
1895 Just, J. A., U. S. 536,633.
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Faucheaux & Bissiere, F. P. 337,598.
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Chilling, Spreading, and Cutting Apparatus

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1867 Guenther, G., U. S. 2,972.
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Kelsey, L., U. S. 681,229.
1908 Kitsee, I., U. S. 883,722.
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1869 Fleck, H., U. S. 90,160.
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1873 Follett, C. S., U. S. 137,835.
Plumer, Wm., U. S. 141,379.
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1911 Honegger, R., D. R. 477,691.
Campbell, C. H., U. S. 1,047,165.
1915 Grosvenor, W. M., U. S. 1,138,751.

Liquid Glue

1830 Gmelin, by heat.
1840 Dumoulin, HNO_3 and oxalic acid.
Fehling, $PbSO_4$ and HNO_3.
1850 Huber, aqua regia.
1850 Fouquier & Mercier, vinegar and alcohol.
1858 Knaffl, L., HCl and $ZnSO_4$.
1882 Horndam, Brit. 22,269 $MgCl_2$ or 8–10% $CaCl_2$.
Bremner, G. W., Brit. 4,035 biphosph. of alumina.
1894 Bolder, Brit. 2,079 chloralhydrate.
1895 Just, J. A., U. S. 536,633, sterilization.
Mills, Brit. 8,847, Bac. liquefaciens.
Brit. 14,936, sal ammoniac.
1896 Mills, U. S. 569,112 alkali and heat.
Martens, Brit. 17,370 salicylic acid.
1897 Bolder, Brit. 19,661 borax.
1906 Dawidowski, $CaCl_2$; $Ca(OH)_2$.
1910 Supf, F., U. S. 974,448 naphthal. sulfonate.
1916 Campbell, C. H., U. S. 1,184,071 3–5% KNO_3.
1919 Alexander, J., U. S. 1,300,096/97 $CaCl_2$ 1/3.

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1881 Brooks, R., U. S. 243,685, dried foam.
1893 Spencer, E. C., Brit. 14,491, flake, shreds
1897 Zimmerman, 2 8391, formo-gelatine.
1900 Kelsey, L. L., U. S. 660,379, pencil glue.
1909 Beckmann, F., Fr. P. 408,254, glue powder.
1915 Scheidemandel, Brit. 15,365, 100,392, globules.
1916 Salm, E., U. S. 1,195,099, globules.

Glue Breaker

1864 Goddard, E., U. S. 44,528.
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THE GERMAN AND AMERICAN SYNTHETIC-AMMONIA PLANTS[1]

Construction and Operation of U. S. Government Plant at Sheffield, Ala., Compared with that at Oppau, Germany

By R. S. TOUR

Read at the Detroit Meeting, June 20, 1922

Great interest has arisen within the last few years in the chemical industry, looking toward the commercial development of synthetic-ammonia plants. Outside the chemical industry the agricultural interests are vitally concerned in the successful development of nitrogen-fixation processes. And in addition, it is of great importance to the United States Government, from a military standpoint, that there be a thriving nitrogen-fixation industry in this country. Although the War Department of the United States built, and attempted to operate as a war emergency, the first synthetic-ammonia plant of commercial size outside of Germany, still it feels that during normal times the development of such processes should be carried on by private interests. The experience and information that has been gained by the War Department will be of value under these conditions in so far as it is made available to the industry. As a step in this direction, the War Department has, therefore, acceded to the request of the American Institute of Chemical Engineers that a paper be submitted describing the German and United States synthetic-ammonia plants.

The direct synthetic-ammonia process has been described in a previous paper[2] by the author, which shows the steps and incidental processes involved in the industrial manufacture of ammonia by direct synthesis from its elements. The purpose of the present paper will be to indicate the methods of operation and types of apparatus and equipment that have been developed in the German and in the American plants. The plants in Germany and the United States are as yet the only industrial synthetic-ammonia plants producing the hydrogen

[1] Contribution from the Nitrate Division, Ordnance Department, U. S. Army. Published by permission of the Chief of Ordnance.

[2] R. S. Tour, *J. Ind. Eng. Chem.*, vol. 12, page 844 (1920).

and nitrogen gases by the water-gas and producer-gas methods. Some other smaller plants have been developed on the Continent for synthesizing ammonia from hydrogen produced electrolytically, but such processes are not generally applicable and have not been considered here.

German Plants

Two plants were built in Germany, one at Oppau with an annual capacity of 100,000 metric tons of ammonia and one at Merseburg with 200,000 tons' rated capacity (respectively 110,000 and 220,000 short tons). Preliminary work on the Oppau plant was started in 1912, and by 1914 a pilot plant of about 10,000 tons' annual capacity was in operation. The main plant construction was started in 1914 and the rated capacity of the entire plant was reached in 1917. The Merseburg plant was built mainly during the war and was operating at three-fourths of its rated capacity before the armistice was signed. The Merseburg plant has since been completed and can now develop its entire rated capacity. Both plants were designed and built by the Badische Anilin und Soda Fabrik after several years of experimental and development work. The same company also operated the plants, although the German Government furnished aid to the company in many ways during the war.

American Plants

One synthetic-ammonia plant was built at Sheffield, Ala., by the United States Government as a war emergency measure in 1917. This plant had a rated annual capacity of 10,000 short tons of ammonia. In the main it followed the principles and processes tried in Germany, but construction was based directly upon experimentation and designs developed by the General Chemical Co. over a preceding period of several years' duration.

After negotiation between the United States Government and General Chemical Co., arrangements were made for the construction and operation of the plant at governmental expense, but according to the company's plans and under its supervision. Experimental operation was started in June, 1918, but continuous operation was not realized up to the time the plant was closed in January, 1919. Another synthetic-ammonia plant is now being built at Syracuse, N. Y., by the Atmospheric Nitrogen Corporation, a company formed by the Solvay Process Co. and the General Chemical Co. It is expected

that this plant will start operations within the year. Several other corporations have been formed in this country within the last few years for the purpose of investigating or developing nitrogen fixation, but as yet none has proceeded with its plans far enough to start construction.

After the Sheffield plant was closed, the Nitrate Division of the Ordnance Department very much desired that the development of the process be continued, but no satisfactory arrangements could be concluded with the General Chemical Co. for the latter to continue experimentation and plant development at Sheffield. The government then felt that it must proceed independently and the United States Fixed Nitrogen Commission was sent to Europe in June, 1919, to investigate the status of nitrogen-fixation there, particularly the Haber plants of Germany. During the summer of 1920, plans and redesigns of the Sheffield plant were undertaken, looking toward the substantial modification of the plant, to be followed by another operating period for further development. The general plans and programs are now nearly complete, but are being held in abeyance, awaiting commercial development of the process by private industry. In the meanwhile, the government desires to aid the industry in any way possible, by making available some of its general information concerning the art.

Products of German and American Plants

The Oppau plant in Germany is the one to be described in this paper, since the writer, as a member of the United States Fixed Nitrogen Commission, during the summer of 1919 was fortunate enough to spend a week at that plant and inspect it thoroughly, submitting a report, dated Nov. 1, 1919, covering this inspection. This report has served as the basis for much of the material and all the sketches relating to the German plant. Previous to the visit to the Oppau plant, the writer had been in direct touch with all the development and initial operation of United States Nitrate Plant No. 1 at Sheffield, Ala., and the descriptions and statements given here concerning that plant are from his report on the work there.

The point of view taken in this comparison of the Oppau and Sheffield plants will naturally be somewhat different for each of the two plants, in view of the fact that the former was in its final stages of development and was an operating success at the time of inspec-

tion, whereas the Sheffield plant was never out of its initial development period.

Only the synthetic-ammonia portions of the respective plants will be considered here, although the German plant included several processes for the utilization of the ammonia, such as (1) the oxidation of part of the ammonia to nitric acid with the final production of ammonium nitrate; (2) the interaction of ammonia and carbon dioxide gas with gypsum to give ammonium sulphate; (3) the reaction of the ammonia-soda process between ammonia and carbon dioxide gas with brine to give ammonium chloride and soda. Auxiliary processes involving the use of carbon dioxide are very attractive in view of the fact that the gas is a by-product in large quantity from the process. At the Sheffield plant there were installed ammonia oxidation, absorption, concentration, neutralization and crystallization plants for the manufacture of the necessary war product, ammonium nitrate.

The Process

Before taking up the description of the plants, it might be well to mention the steps involved in the synthetic-ammonia process.

Manufacture of Hydrogen and Nitrogen.—Hydrogen is obtained by the "water-gas oxidation" method, wherein water-gas produced in standard machines is caused to react further with an admixture of steam in the presence of a catalyst according to the reaction $CO + H_2O \rightleftarrows CO_2 + H_2$, converting (oxidizing) most of the carbon monoxide to dioxide and generating additional hydrogen in so doing. The nitrogen in the mixture may be obtained by supplying air into the gas generator during the manufacture of the water-gas, or by the injection of air into the oxidation stage of the process, or by the admixture of straight producer-gas to the water-gas before oxidation.

Purification of the Gases.—The purification of the gas mixture is accomplished by high-pressure water-scrubbing to remove carbon dioxide, followed by ammoniacal cuprous solution scrubbing to remove carbon monoxide and incidental impurities. Auxiliary or special purification may further involve scrubbing with hot or cold caustic solutions, drying with soda lime or similar treatment.

Manufacture of the Ammonia.—The synthesis of the ammonia is finally accomplished in one portion of a continuous circulating system by passing the nitrogen-hydrogen mixture at high pressure and high temperature over a suitable catalyst. The ammonia synthesized is

removed continuously by liquefaction or absorption in another portion of the circulating system, while the uncombined gases repeat the cycle together with additional gas mixture introduced to replace that synthesized.

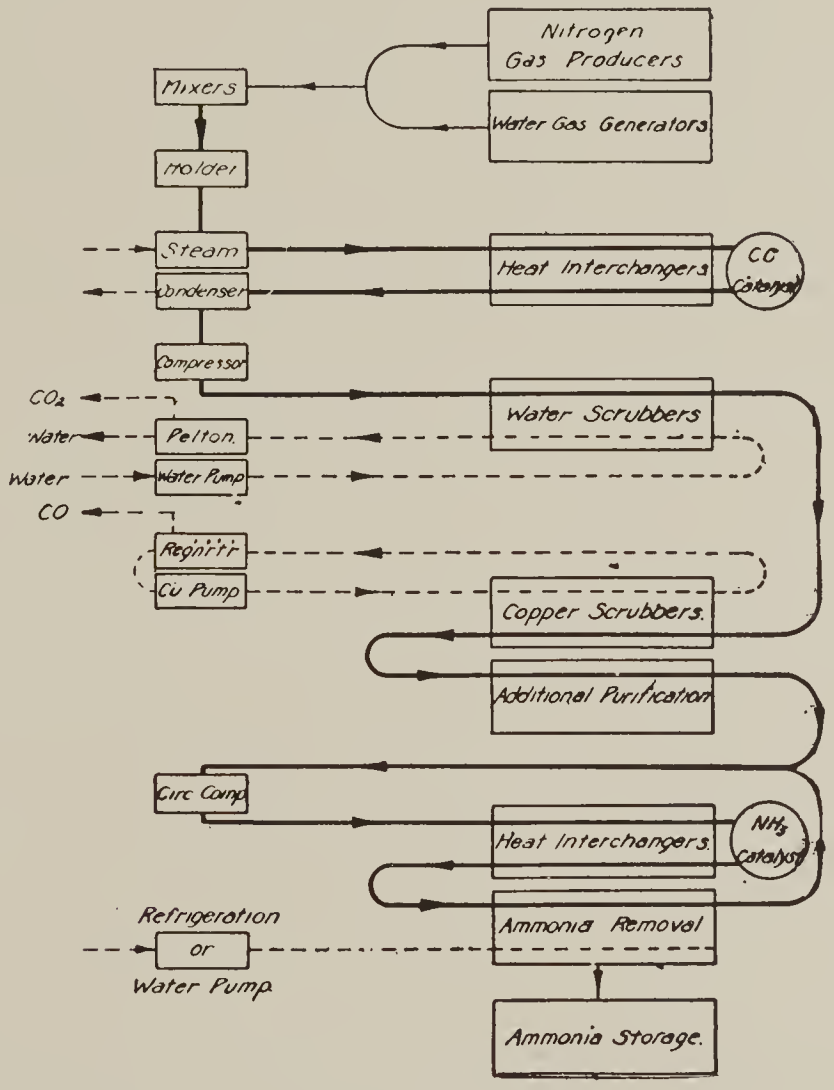


FIG. 1—Diagrammatic Flow in the Direct Synthetic-Ammonia Process

GENERAL FACILITIES OF THE OPPAU PLANT

The German plant is situated at Oppau, on the Rhine, about two miles below Ludwigshafen and about a mile from the main chemical plant of the Badische Anilin und Soda Fabrik, which controlled the plant and process.[3] The Oppau plant covers 175 acres of ground and much more is available if necessary. There are about 250 buildings or structures of various sizes and shapes. All the main buildings are substantially built of brick and steel and are logically arranged with carefully laid-out streets. Necessary trackage, transportation facilities, cranes, etc., are provided throughout.

[3] Reference should be made to the articles on the "Manufacture of Synthetic Ammonia at Oppau, Germany," published in *Chem. & Met. Eng.*, vol. 24, pp. 305–8, 347–50 and 391–4 (1921).

Primary central power for the plant is furnished by a producer-gas-engine installation of 10,000-kw. capacity and a steam turbine station of 18,000-kw. capacity. Electric power is generated and distributed at 3,000 volts, three phase, fifty cycles. In addition there are steam and gas engines for local power production at various points throughout the plant. Comparatively little of the central station power is consumed for the synthetic-ammonia manufacture, since, where compressors or pumps of large capacity operate continuously, they are directly driven by gas or steam engines.

High-pressure steam (175 lb.) is furnished by water-tube boilers equipped with superheaters, mechanical grates and forced draft. The total heating surface is about 60,000 sq. ft., divided among thirty-two boilers of several sizes. The fuel is normally lignite, although some of the boilers are equipped for burning tar and oil and others for producer-gas. Low-pressure steam (50 to 60 lb.), necessary in different parts of the process, is supplied by tubular boilers heated by gas-engine exhaust.

The main fuel for the plant is lignite in the form of briquets available near by in the valley of the Rhine. These are used for steam generation and for the producer- or power-gas manufacture. Considerable hard coal, or anthracite, is also used. The coke needed was purchased during the war, awaiting the completion of the by-product coke-oven installation on the grounds. The total fuel consumption of the plant at capacity, including ammonia utilization processes, is about 2,500 short tons per day, most of which is delivered from barges on the Rhine and taken care of by elaborate coal-handling equipment.

Water is supplied by a pumping plant on the Rhine, operated with electric power and also by gas engines. All the water is filtered through sand and finally supplied to the plant at a pressure of 60 to 70 lb. The total water-plant capacity is about 100,000 gal. per minute.

Shops and Laboratory at Oppau

The plant has large machine, pipe and repair shops. The equipment of these shops is complete in every respect and large enough to take care of the largest piece of apparatus in use at the plant. The administration offices and main research laboratory are housed in a beautiful building, fully and completely equipped, costing in all about 3,000,000 marks. This building is in addition to the different routine

testing laboratories and superintendents' offices located in the individual buildings where operating control is necessary.

Each step of the process is housed in a separate building and in many cases the high-pressure apparatus is outside of, but adjacent to, the building assigned to it. The building itself contains the pumps, engines and other auxiliary apparatus together with the control valves and lines, which are carried through the walls from the apparatus outside and thus safety and shelter are afforded to the operators. Each step of the process involves several identical items of apparatus, operating in parallel; thus allowing the failure or repair of any single item without jeopardizing the balance of the process. The number of items installed is different for the respective steps of the process. No series of apparatus for all the steps is connected to form complete independent units for the entire process, but the entire plant works as one single unit with a productive capacity of 300 tons of ammonia per day.

General Facilities of the Sheffield Plant

The American plant is situated on the outskirts of Sheffield, Ala., about a mile from the Tennessee River. The plant proper occupies about 100 acres, although the plant has title to much more surrounding property. There are perhaps forty buildings, some of which are of a temporary nature, although the main process buildings are of substantial and modern construction.

Primary power for the entire plant is furnished by turbo-generators totaling 5,000 kw., generating at 2,200 volts, three phase and sixty cycles. There is no power generation about the plant other than the above. The power that is used for the synthetic-ammonia process is transmitted through rotary converters and used at 250 volts d.c. The main purpose of the d.c. power was to allow a more flexible speed control in the operation of the synthetic process plant.

High-pressure steam (190 lb.) is obtained from eight Stirling boilers of 500 b. hp. each, equipped with superheaters, stokers and forced draft. There is no installation for low-pressure steam, but this is obtained through a reducing valve from the high-pressure main or is "bled" from the turbines. The fuel is bituminous coal except in the gas generators, where coke is necessary. The coal and coke are brought into the plant grounds by rail and are normally obtained from near-by localities.

The use of direct-current power at Sheffield, Ala., is a definite

inefficiency which is chargeable to the development of the process at that plant. In view of the fact that low-pressure or exhaust steam is necessary, it would have been much more advantageous to operate the experimental equipment in place with reciprocating steam engines properly equipped with throttle or cut-off adjustments, these engines exhausting into the exhaust manifold for supplying the steam requirements of the plant. High-pressure steam used for low-pressure purposes is expensive and the bleeding of steam turbines puts them at a disadvantage in comparison with reciprocating engines.

Water is supplied by a pumping station situated about two miles distant near a large spring and creek having the necessary capacity all year round. There is a filter plant on the plant grounds where all the water used may be filtered through sand and finally supplied to the plant at a pressure of 40 to 50 lb.

Shops and Laboratory at Sheffield

The plant has but one small machine shop and general repair shop and the equipment there installed is not sufficiently large to take care of the larger pieces of apparatus connected with the synthetic-ammonia process. If such work should become necessary, the apparatus would have to be shipped to a properly equipped machine shop in some other locality. The administration and control laboratory buildings are of temporary nature and have been held over from the construction period. The plan was to erect permanent buildings in accordance with their necessity at some later date.

The lack of large enough and properly equipped machine and repair shops was found to be a serious handicap immediately after starting operation. The omission of a crane for moving the heavy apparatus in the main ammonia process building was another serious oversight. The lack of an administration building was not seriously felt, but the need of a properly equipped research laboratory with the necessary personnel immediately became evident. The latter is a very necessary adjunct to the process in such a stage of development as it was at Sheffield.

Practically all the steps of the process are housed in one large building. All the high-pressure apparatus, together with pumps, motors and controls, are also within the building. Only the water-gas machines and their auxiliaries are separately housed. It is evident that this general scheme is undesirable in a commercial plant,

especially one in a developing stage, since the rupture or explosion of one piece of apparatus endangers the entire equipment of the process. The crowding necessary to place so much equipment under one roof caused many inefficiences in proper development or operation.

The gas purification and ammonia-synthesis portion of the plant consists of three separate and independent units not interconnected although in the same building. The different steps of the process in each unit involve but single items of apparatus with spares where considered necessary. The operation of independent units with but single items of apparatus in some of the steps requires the shut-down of the complete unit in case of a failure to function of any single item. In view of all these handicaps it speaks well for all concerned that operation resulted in no serious mishaps and that success seemed finally within grasp.

Unit No. 1, the only unit upon which complete operation was attempted, and Unit No. 2 were rated at 15,000 lb. of anhydrous ammonia each per day. Unit No. 3, which was never completely installed, carried larger apparatus than the other units and was rated at 30,000 lb. of ammonia per day.

Water-Gas Production at Oppau

There are, in reality, four distinct types of gas produced at Oppau: (1) Water gas made from coke, as the main source of hydrogen for the synthesis of ammonia, (2) lean gas as the main source of nitrogen for the ammonia, (3) power gas (producer) as the main source of power throughout the plant, and (4) nitrogen from liquid air for adjustment of gas composition in the synthesis of ammonia. These gases and gas mixtures are generated by standard methods and equipment.

The water gas and lean gas are made in 12-ft. shell Pintsch type generators of which there are 15, 12 with, and 3 without, revolving grates. In addition there are two or three experimental generators where an attempt is being made to develop a lignite burning water-gas machine, and a slagging type producer. The fuel used is a high grade of coke normally to be delivered from by-product coke ovens on the grounds. These ovens are to have a capacity of 700 tons of coke per day, the excess gas from which may be used for power purposes.

The water-gas machines deliver about 2,500,000 cu. ft. each per day (60 deg. F. and 30 in. Hg) with a fuel consumption of 40 to 42

lb. per thousand. The normal operating capacity of the water-gas machines is 25,000,000 to 30,000,000 cu. ft. per day, with a coke consumption of 550 to 650 tons. The generators are operated on one- to two-minute "blows" and three- to five-minute "runs," the latter being "up," "down," or "mixed," according to requirements. The steam used is 175 lb., 125 deg. F. superheat. The water-gas composition is approximately: 4 per cent CO_2, 43 per cent CO, 49 per cent H_2 and 4 per cent N_2. Attention is called to the fact that a high nitrogen content is not objectionable here since there is to be a later admixture of high nitrogen gas; hence any steps tending to decrease the loss of hydrogen in the stack are desirable, even though they add nitrogen to the gas.

The lean gas (producer gas made from selected fuel) consists merely of water gas to which is added the blast gas of the blow period. This allows of continuous, rather than intermittent, operation of the machines producing this gas. In the water-gas machines the blast-gas volume is nearly twice the water gas generated. Thus the capacity of the machine producing lean gas is about 7,000,000 cu. ft. per day, with a fuel consumption of about 15 lb. per thousand. The lean gas required is about half the water gas; hence two generators supply the necessary capacity and consume some 100 tons of coke per day, coke being used to produce a methane-free gas. The lean gas composition is approximately 5 per cent CO_2, 30 per cent CO, 15 per cent H_2 and 50 per cent N_2.

The water gas and lean gas pass separately through standard wash-boxes and water scrubbers packed with Raschig rings and on to two water-gas storage and relief holders of 500,000 cu. ft. capacity each, and one lean gas holder of like size. There are no purifiers for the gas and no waste-heat boilers on the machines.

Manufacture of Producer Gas at Oppau

Producer gas (power gas) is made according to standard procedure in twenty-three B.A.M.A.G.[4] continuous producers with revolving grates. These are situated in the same building with, and in a row directly opposite, the water-gas machines mentioned above. The machines are of 16-ft. shell diameter and burn a fuel of part lignite briquets (2 in. by 4 in. diameter cylinders) and part hard coal, the latter being advisable for maintaining good fuel bed conditions

[4] Berlin Anhaltische Maschinen Aktien Gesellschaft.

and producer capacity. The producers deliver about 2,500,000 cu. ft. per machine per day, with a fuel consumption of 20 to 22 lb. per thousand (at 60 deg. F. and 30 in. Hg). This gives a plant capacity of about 50,000,000 cu. ft. per day and a daily fuel consumption of about 500 tons.

In view of the high combustion rate for the type of fuel in the producers, a low steam proportion is used, a high fuel bed temperature is maintained and the gas made is high in nitrogen and of low heating

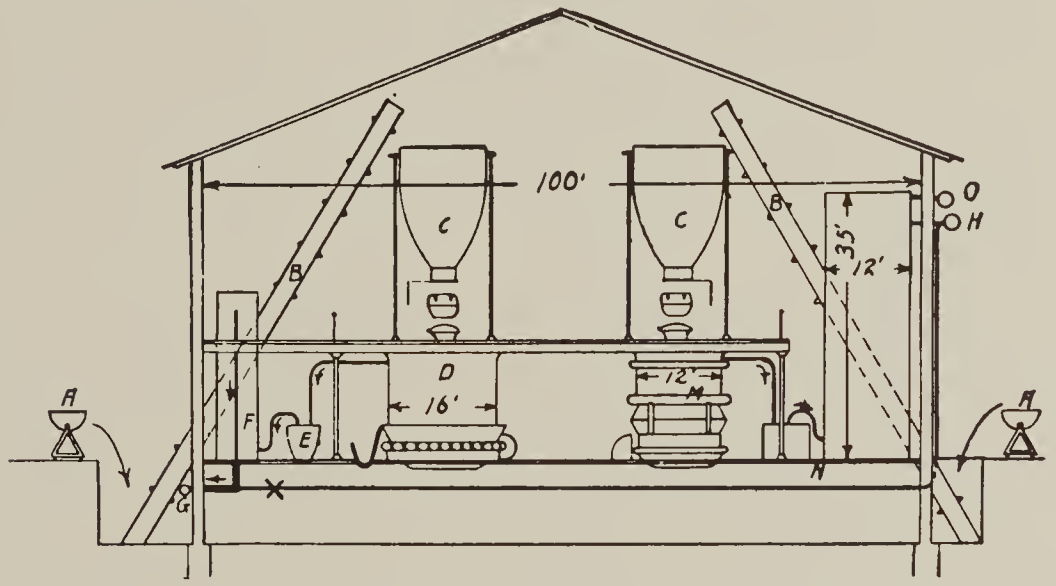


FIG. 2—Producer and Water-gas Generators at Oppau

A, cars for lignite and coke; *B*, conveyors; *C*, hoppers and charging buggies; *D*, power-gas producer; *E*, hydraulic main; *F*, water scrubbers; *G*, main to power-gas holder; *H*, main to lean-gas holder; *M*, water-gas generator; *N*, wash box and water scrubber; *O*, main to water-gas holders.

value. A mean composition would be 4 per cent CO_2, 27 per cent CO, 4 per cent H_2, 2 per cent CH_4, and 63 per cent N_2. The purification of the producer gas is naturally more extensive than that of the water gas. First, a standard water scrubber is used, followed by a centrifugal water washer or tar extractor and a cyclone separator. The clean gas then passes to a 2,000,000-cu. ft. holder feeding the gas engines throughout the plant.

PRODUCTION OF PURE NITROGEN AT OPPAU

Free nitrogen is necessary for incidental purposes about the plant and large quantities are essential for continuous adjustment of the composition of the hydrogen-nitrogen mixture required for the synthesis. The mixing of the water gas, described above, with the lean gas yields a mixture somewhat low in nitrogen and purposely made

so, since nitrogen in variable quantities in the form of air is to be later added for internal combustion and heat maintenance. The variation in this combustion air, as well as operating variations in gas compositions and in proportioning of lean gas to water gas, may lead to quite wide variation from the 3:1 hydrogen-nitrogen mixture finally required for ammonia synthesis. Since any slight excess of either constituent rapidly accumulates in the ammonia-synthesis circulating system where the ammonia removed represents exactly three parts hydrogen to one part nitrogen, it becomes necessary continuously to adjust the composition of the gases. It is obvious that this adjustment is more economically made by adding pure nitrogen rather than pure hydrogen, and hence the initial gas mixture is purposely maintained sufficiently low in nitrogen to allow for more than the subsequent operating variations.

The nitrogen plant at Oppau consisted of 6 distillation columns of the Linde type and 7 air compressors direct-connected to gas engines. The installation was old and a new plant has been built similar to the above and having a capacity of about 1,800,000 cu. ft. of nitrogen per day. If half of this capacity is regularly used for adjustment of composition, it represents about 13 per cent of the nitrogen fixed and allows for an average nitrogen deficiency of 3 per cent of the total gas mixture entering the ammonia synthesis system.

The water gas, as a source of hydrogen, and lean gas, as a source of nitrogen, are delivered from their respective holders by turbo-exhausters equipped with water injectors for saturating the gas and followed by cyclone separators for removing excess water. The gases then pass through meters and to a mixing main equipped with turbo-blowers for mixing the gas and for feeding it to the converter system. The two gases are fed to the mixing main in such proportions as finally to yield a purified gas, which, as previously explained, is somewhat deficient in nitrogen.

Water-Gas Production at Sheffield

There was but one type of gas produced at Sheffield: viz., a water gas with varying nitrogen content—this gas being produced according to standard methods and in standard equipment. The latter consisted of six 7½-ft. shell water-gas generators; the fuel used was a high grade of coke.

The capacity of each water-gas machine at Sheffield was about

0.7 million cu. ft. of water gas per day. The plant capacity was about 3,500,000, or about sufficient for the rated ammonia capacity. However, the contemplated operation called for a number of gas-fired furnaces in conjunction with the process and had their use not proved unnecessary, the gas plant would have been much under capacity. The water gas from the machines passed through standard wash boxes and water scrubbers and on to a storage and relief holder of 500,000 cu. ft. capacity. From this the gas was fed by holder pressure through iron-oxide purifying boxes on the way to the carbon-monoxide converters. The purifiers caused some trouble due to excessive friction and were soon found to be unnecessary. It will be noted that the Germans did not use any purification process.

Methods of Supplying Nitrogen at Sheffield

The plant had been designed to operate on a high-nitrogen water gas where all the nitrogen necessary for the later synthesis was injected as air into the generator during the gas-making period. This method, although generating a mixed gas, is not fundamentally different from the procedure used at Oppau, though the former may be more adaptable for small plant use. In either case, the nitrogen comes from blast gases since the air used has made available heat within the fuel bed. Where possible, it is naturally more desirable to operate one of the machines as a continuous producer and the other machines for straight water-gas production. The Sheffield plan of using only part of the blowing air in each machine simultaneously with steam during gas production involves many operating difficulties, the most important of which is the variable composition of the effluent gases. Although both the air and the steam can be measured, the

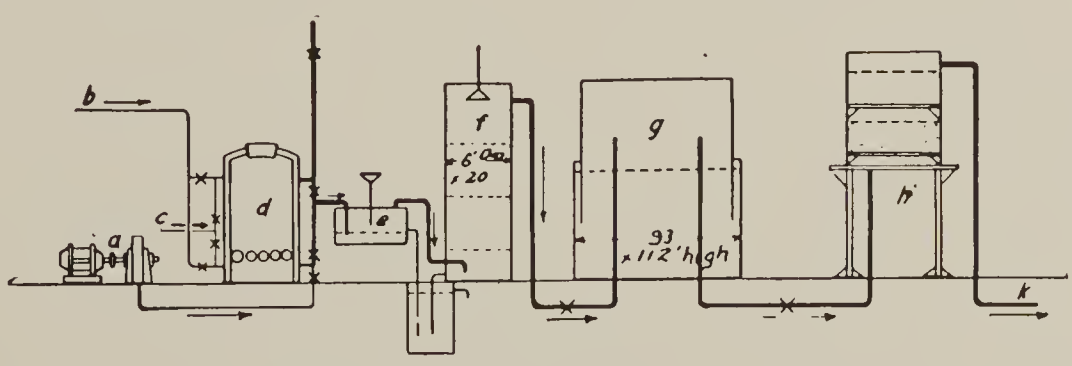


Fig. 3—Water-gas Generator at Sheffield

a, sirrocco blower, motor driven; *b*, auxiliary air inlet to gas generator; *c*, steam inlet to gas generator; *d*, water-gas generator; *e*, wash box; *f*, scrubber; *g*, holder; *h*, iron-oxide purifier; *k*, gas exit to CO converter.

proportion of steam decomposed, and therefore the resultant proportion of hydrogen, will be dependent upon the grade of fuel, upon the temperature and cleanliness of the fuel bed, and upon operating variables in general, and will also vary enormously from the beginning to the end of each "run."

It was found that later in the process very considerable air injection into the carbon-monoxide converters was required for internal combustion and maintenance of temperature, and this reduced the quantity of nitrogen the mixed gas might carry from the water-gas machines. In view, therefore, of the difficulties in operating the gas machines and the actual low nitrogen content desired, the final operation at Sheffield developed into straight water-gas manufacture with all of the nitrogen added later by air injection. The latter type of operation, although it may be necessary, is fundamentally inefficient, since air injection into the gas with combustion of the latter involves a definite loss of hydrogen or carbon monoxide (which later yields hydrogen), whereas the nitrogen available from the gas generator blast represents no loss of fuel. Complete nitrogen supply by air injection and combustion in the gas involves a loss of 25 per cent of the hydrogen obtainable from a given volume of water gas with

NITROGEN SUPPLY BY AIR INJECTION AND COMBUSTION

Carbon dioxide	40	177	40	449	29.2
Carbon monoxide	440	303	440	31	2.0
Hydrogen	520	520	383	792	51.6
Nitrogen		264	264	264	17.2
	1,000 Cu. Ft.			1,536 Cu. Ft.	100.0

NITROGEN SUPPLY BY BLAST-GAS ADDITION

Carbon dioxide	40	61	601	29.2
Carbon monoxide	440	581	41	2.0
Hydrogen	520	520	1,060	51.6
Nitrogen		352	352	17.2
	1,000 Cu. Ft.		3,054 Cu. Ft.	100.0

nitrogen added as blast gas, and thus increases the fuel consumption by 33 per cent.

The results given in the preceding tables have been calculated on the basis of identical operation and efficiency in each case. It is to be noted that it makes no difference whether carbon monoxide or

hydrogen is burned by the air in the first case; values are, however, given for both.

During operation at Sheffield the blue water gas produced had the approximate composition: 4 per cent CO_2, 44 per cent CO, 50 per cent H_2, and 2 per cent N_2. The coke consumption was about 60 lb. per thousand cubic feet, and the labor charge high. A high fuel and labor charge is to be expected in view of the small size of the machines. After the close of plant operation, the Nitrate Division tried an improvement on the machines with great success. This consisted mainly of secondary blast within the fuel bed, allowing more rapid and uniform heating during the blow and improving the fuel efficiency by reducing carbon-monoxide losses in the blast gases. Test showed that the fuel consumption had been reduced to 40 lb. of coke, or equally as good as the German operation with their 12-ft. machines.

There was no pure nitrogen produced at Sheffield for adjustment of composition. Experience with the control of the nitrogen content, however, proved that had the plant produced any quantity of ammonia, adjustment of composition would have been necessary. Thus, had the hydrogen to nitrogen ratio been 3.3 to 1.0 (and that is not bad operation) rather than 3.0, capacity operation within three or four hours would have caused the ratio in the ammonia synthesis system to reach 5 to 1.

Carbon-Monoxide Conversion at Oppau

The mixture of lean gas and water gas after being proportioned properly has the approximate composition: 4 per cent CO_2, 39 per cent CO, 38 per cent H_2, and 19 per cent N_2. This mixed gas has added to it a large excess of steam and passes through heat interchangers to the converter where a catalyst aids the exothermic water-gas reaction: $CO + H_2O \leftrightarrows CO_2 + H_2$. The converted gas passes back through the heat interchangers followed by a condenser to remove excess steam.

The steam addition at Oppau is accomplished by an apparatus which we may call a steam interchanger, whereby much of the steam condensed from the converted exit gas is made available to the inlet mixed gas. This cooling and condensation of exit gas is brought about by direct contact with a counter-current spray of cold water in a condenser shell 12 ft. in diameter and 60 ft. tall, filled with suitable

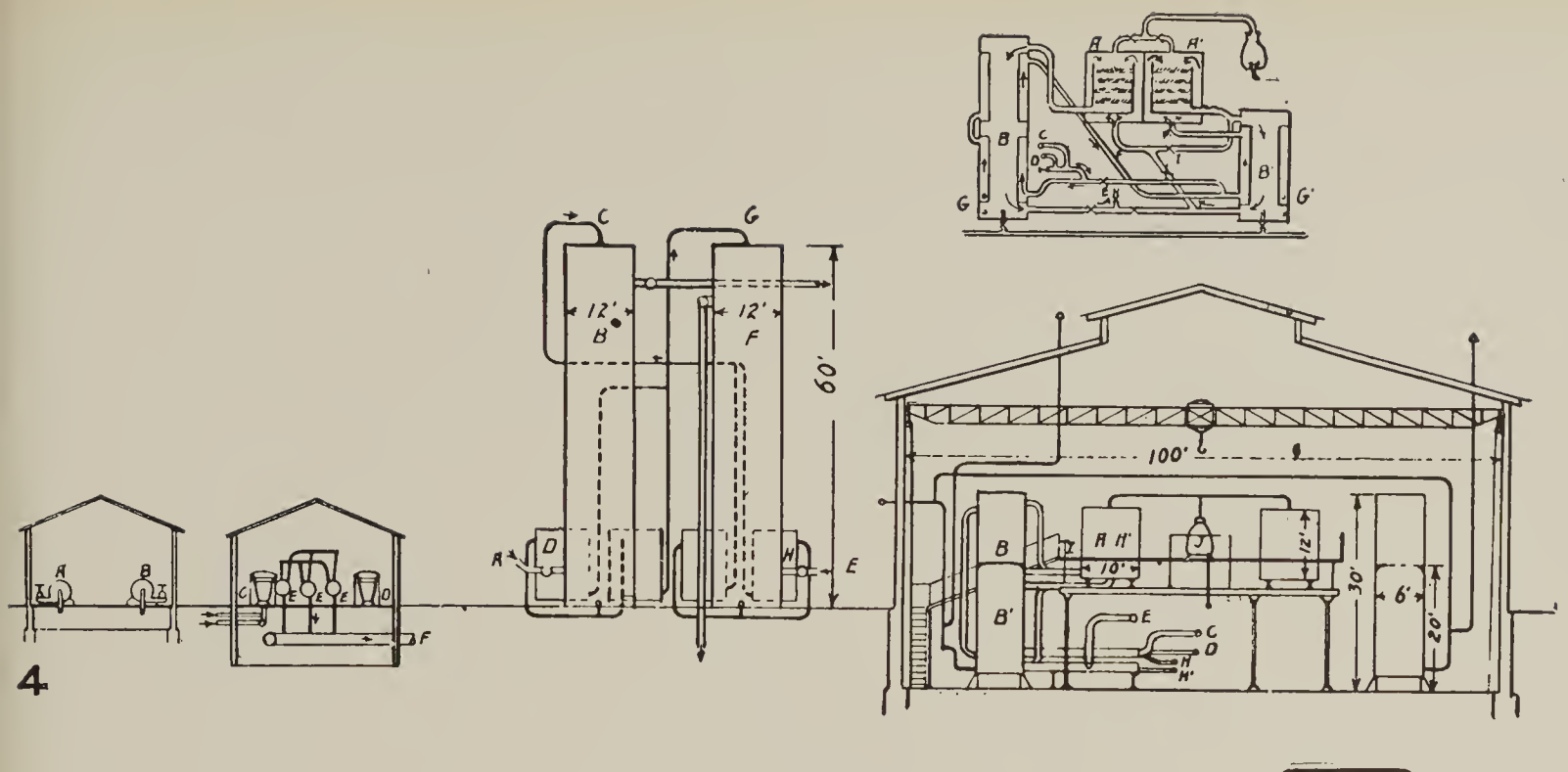
packing. The water emerges from the bottom of the condenser at nearly boiling temperature and is fed to the vaporizer, similar in all respects to the condenser, where the cold inlet gas is heated and supplied with steam from the hot water. The water is cooled by this treatment and again repeats its cycle through the condenser.

Two sets of steam interchangers handle the entire plant capacity, interchanging some 1,350 tons of steam per day per set. The total steam required in the nearly 40,000,000 cu. ft. of inlet-mixed gas is about 4,000 tons (*i.e.*, 4 volumes per volume of inlet gas), 300 tons of which actually react. An additional 1,000 tons of the 4,000 are not interchanged but lost as condensate. The 2,700 tons that are interchanged to the inlet gas are augmented by 1,300 tons of low-pressure steam injected into the mixture just before it enters the converter system.

Path of Gases at Oppau

There are 24 converter sets, complete with heat interchangers, 12 sets in each of two adjacent buildings. All sets are fundamentally the same and have a capacity of about 75,000 cu. ft. of dry inlet gas per hour. In each building the sets operate in parallel, taking inlet gas and steam from a single main and discharging to one main. The path of the gases in each set is through a large interchanger followed by a small one, which raise the gas temperature to some 500 deg. C. when it passes through the carbon-monoxide catalyst, there further rising in temperature about 60 deg. C. due to reaction heat. All but about 3 per cent of the carbon monoxide in the gas is converted at this point. The gas then passes back through the smaller heat interchanger, giving up heat, and then through a second catalyst bed at a lower temperature, at the entrance to which air is injected and, if necessary, additional steam. The carbon monoxide is here reduced to 1.5 per cent and the gas passes on through the last large heat interchanger.

The heat interchangers consist of large sheet-iron shells with an internal nest of tubes; the inlet gas passes around the tubes and exit gas through the tubes. This path is by far the better, since the external radiation losses are decreased, as well as the temperature transfer head improved. The larger interchanger is about 6 ft. in diameter by 30 ft. high, while the smaller is 6 ft. by 20 ft. high. Both shells are lagged with about 8 in. of magnesia.



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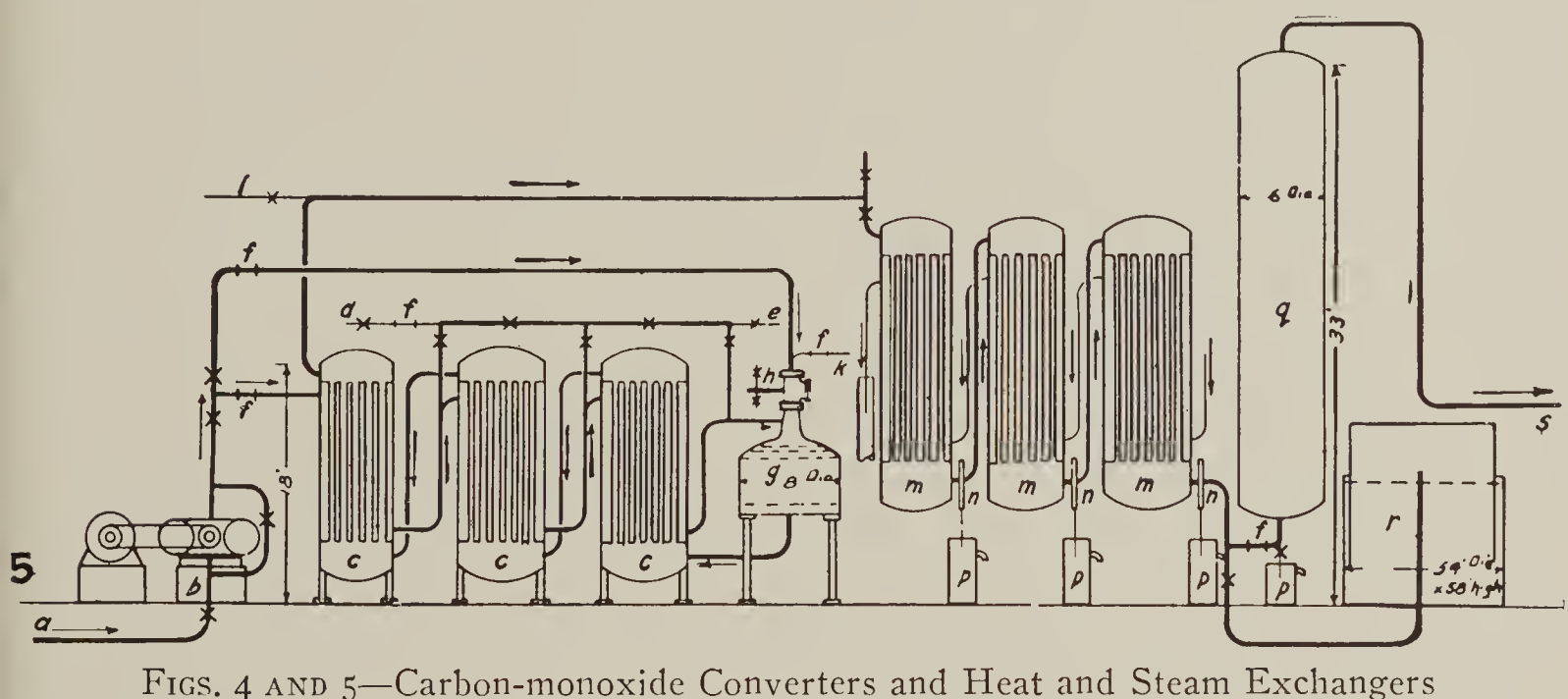

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FIGS. 4 AND 5—Carbon-monoxide Converters and Heat and Steam Exchangers at Oppau (above) and Sheffield (below)

Fig. 4 (above). Meters and mixers at Oppau (at left). *A*, gas exhauster from water-gas holder; *B*, gas exhauster from lean-gas holder; *C*, gas meters to mixers; *D*, gas meters for converted gas; *E*, 3 turbo ventilators for mixing; *F*, mixed gas discharge main to steam interchanger.

Steam interchangers at Oppau (center). *A*, cold raw gas mixture; *B*, heating and evaporating tower; *C*, hot water inlet to *A*; *D*, cold water reservoir from *A* and feeding to *G*; *E*, hot converter gas inlet; *F*, cooling and condensing tower; *G*, cold water inlet to *F*; *H*, hot water reservoir from *F* and feeding to *C*.

Carbon-monoxide converter and heat interchangers at Oppau (at right). *A-A'*, catalyzers; *B-B'*, large and small heat interchangers; *C*, raw gas inlet; *D*, steam inlet; *E*, converted gas and steam exit; *F-F'*, auxiliary air and steam injection; *G-G'*, nitrogen inlet for flushing; *H-H'*, flushing exit; *I*, main control valve for by-passing small interchanger; *J*, starting burner using producer gas.

Fig. 5 (below). Carbon-monoxide converter, heat exchangers and condensers at Sheffield. *a*, gas inlet from holder; *b*, Connersville blowers, motor driven; *c*, heat exchangers; *d*, steam inlet to heat exchangers; *e*, hot air inlet for starting system; *f*, Venturi meters; *g*, catalytic chamber; *h*, auxiliary burner (on catalytic chamber); *k*, air inlet to burner; *l*, gas vent from system; *m*, condensers; *n*, separators; *p*, overflow; *q*, buffer tank; *r*, gas holder; *s*, gas exit to compressors.

The Catalyst Beds at Oppau

The two catalyst beds are in a heat-insulated shell about 12 ft. tall. A horizontal cross-section of the shell would be rectangular (10 ft. by 30 ft.) with round corners. A vertical partition divides the shell into two independent compartments. The catalyst in each compartment is placed on 5 superposed trays in a container to conduct the gas downward through the catalyst.

The use of two catalyst beds in series, the second at a lower temperature, represents a decided improvement in operation. The water-gas reaction, as well as the later ammonia reaction, has a much more favorable equilibrium at lower temperatures, but also a much slower reaction rate. Thus, it is desirable to accomplish most of the reaction at higher temperature and follow that by low-temperature catalysis. If air or oxygen be available during low-temperature catalysis, the oxidation of the carbon monoxide will be much more readily carried to its equilibrium value. Further, the air supply may be adjusted to supply internal heat within the system, if such be necessary for maintenance of temperature. The catalysts used for the carbon monoxide conversion depend for their activity mainly upon iron oxide with chromium oxide as a promoter. Cerium and thorium oxides have also been tried as promoters.

Great care is taken in the control of the converters. Each set is supplied with some 50 base-metal thermo-couples reading on an indicating millivoltmeter. There are manometers to read pressures in different parts of each set and Pitot tubes to measure flow of steam and gas and air. The gas obtained at the exit of the converter sets has the approximate composition: 29.5 per cent CO_2, 1.5 per cent CO, 53 per cent H_2, and 16 per cent N_2. The volume of inlet gas has been increased about 35 per cent in the converters, so there is a daily converted gas production of 50,000,000 to 60,000,000 cu. ft. (representing 25,000,000 to 30,000,000 cu. ft. of hydrogen). This converted gas, after condensation of moisture, passes back to the metering house where the inlet gas was measured and mixed. After the gas has been metered, it passes to another 500,000-cu. ft. holder, from which it is directly available to the compressors.

Carbon-Monoxide Conversion at Sheffield

The conversion process used at Sheffield was much the same as that at Oppau, especially so toward the close of operation. The gas

from the holders was delivered to the converter set by positive pressure exhausters. No steam interchangers were used, but all the steam, 200 lb. per thousand cubic feet of gas (about 4 volumes per volume of inlet gas), was fed from the steam main and all the excess steam on the exit gas was condensed. This method of operation requires about three times as much steam and condensing water as does the method described for Oppau. The steam supply, as the plant was installed, was to feed through a standard gas-fired tubular steam superheater which was to furnish the additional heat required to maintain the converter system at operating temperature. This method of heat supply is inefficient in two ways: (*a*) The steam superheater efficiency is directly involved and this is low, especially for the large superheat required at Sheffield, and (*b*) heating the inlet mixture decreases the temperature head across the heat interchangers and their heat transfer is proportionally decreased. On the other hand, air injection for internal combustion of gas at the catalyst chamber yields nearly 100 per cent thermal efficiency and also increases the temperature head across the interchangers, thus improving their heat transfer. After burning out the steam superheater, the internal-combustion method was tried with great success and with a large saving in gas consumption. The steam then was injected as low-pressure steam.

The condensation of the excess steam at the exit of the system was accomplished by two surface condensers operating in parallel. These were soon found to be of only a fraction of the necessary capacity and additional condensers were installed. Very little experience is available for the design of condensers for a mixture of 75 per cent steam and 25 per cent gas. Some experiments made by the Nitrate Division looking toward the redesign of the condensers indicate that the coefficient of heat transfer under such conditions is of the order of one-tenth that in standard condensers. The actual value, however, is largely dependent upon the lineal velocity of flow of the steam-gas mixture and of the water. Efficient condensation at the exit of the carbon-monoxide system is important, especially if the mixture passes on directly to the compressors, as it did at Sheffield. The condensate is of no value, due to dissolved gases, and the only reason for using surface, instead of jet condensers, would be to make use of the heated cooling water.

Converter Operation at Sheffield

There was but one carbon-monoxide converter set with a rated capacity of 30,000 cu. ft. of inlet gas per hour, in the operating unit. (Unit No. 1.) This consisted of one catalyst chamber with three heat interchangers, the inlet gas passing through the first and smallest of the three before steam injection. The general construction of the interchangers was much the same as that described for Oppau, although with much less transfer surface. The heat transfer through the interchangers was not very satisfactory and accounted for the fact that the system was so far from self-maintaining in temperature.

There was but one catalyst chamber, of circular section, 8 ft. in diameter and 6 ft. deep, into which was first charged 120 cu. ft. of catalyst in a single bed about 2½ ft. deep. In operation this bed rapidly developed high friction to gas flow, due to crumbling and packing of the catalyst, which is physically delicate and can not withstand the accumulated friction and weight of a deep bed. The converter was repacked with about half the depth and operated quite satisfactorily thereafter, although the Oppau method of placing the catalyst in shallow layers on superposed grids is the best solution.

During operation the catalyst inlet temperature was maintained at 500 deg. C. and the rise in temperature across the catalyst bed was 50 to 60 deg. C. As mentioned before, this heat liberated was far from sufficient to maintain the system at its proper temperature and air was injected for internal combustion at the top connection of the converter through what was known as the auxiliary burner. The air combined with the gas as a flame above the catalyst and not within the catalyst bed. Flame combustion is the better method where any large quantity of heat development is necessary since it prevents too large a temperature gradient through the catalyst bed itself. No provision had been made for ignition of the auxiliary burner, but this difficulty was soon overcome. The more flame used, the more nitrogen is added and the less is to be introduced at the gas house.

Operation at Sheffield required that about 75 per cent of the total nitrogen be added at the burner and finally, in view of the difficulty of nitrogen control in the gas machines, all of it was added through the burner, the excess heat developed being wasted partly by passing the heat interchangers.

No secondary converter was used at Sheffield, although the writer, without being acquainted with the process in use at Oppau, tried ex-

perimentally in November, 1918, what he called an "oxidizer" in the converter set of Unit No. 2 (not the one in operation). The oxidizer was merely an additional converter connected in the line of the return gas from the primary converter after the gas had passed through one heat interchanger. The oxidizer was charged with the same catalyst as the primary converter, operated at a lower temperature than the latter, and had air injection, but not through a burner, oxidation being desired within the catalyst. For various reasons the experiment was not continued long enough to give decisive data. However, the standard operation at Oppau is somewhat similar to that attempted with the "oxidizer."

During operation, temperatures were measured by 4 or 5 platinum resistance pyrometers; pressures were indicated by manometers in the system; and gas, steam and air inlet volumes were measured by Venturi meters. The converted gas composition was about 29 per cent CO_2, 3 per cent CO, 51 per cent H_2, and 17 per cent N_2; the residual carbon monoxide was about the same as at the first catalyst in Oppau, although the nitrogen was higher, since no further nitrogen addition was contemplated. The converted gas passed directly from the condensers to the compressors, a Venturi meter on the line measuring the compressor intake. In the suction line to the compressors was connected a large buffer tank to absorb the pulsations and also a 75,000-cu. ft. holder to take up slight variations between supply and demand.

The first undesirable constituent to be removed from the converted gas is the carbon dioxide, which is eliminated by water scrubbing of the gas under pressure. The pressure used at Oppau is but 25 atmospheres for the water scrubbing, although 200 atmospheres pressure is used through the rest of the process. The compression is accomplished by 12 five-stage compressors (3-9-25-70-200 atmos.). After the third stage the gas is withdrawn and scrubbed, and then returned to the fourth and fifth stages. The compressors require about 1,000 hp. each, and are separately driven by direct-connected producer-gas engines. The compressors are of standard design with equal capacities in all stages, but since water scrubbing after the third stage removes about 35 per cent of the gas (CO_2 and some H_2 and N_2) there are provided 5 additional three-stage (25 atmos.) compressors to handle the larger capacity necessary in the lower stages before water scrubbing.

Carbon Dioxide Removal at Oppau

There are 12 water-scrubbing towers, 4 ft. in outside diameter and 40 ft. tall, made in two 20-ft. sections, bolted together in the middle. All operate in parallel, taking compressed gas from a manifold fed by the 17 compressors previously described. The gas passes up through the tower packing, consisting of Raschig stoneware rings (3 in. by 3 in.) while water flows downward through the packing to a reservoir at the base of the tower. The exit gas from each scrubber passes through a mist trap or catch-pot before passing on to the fourth stage of the 12 high-pressure compressors. The mist trap is bottle-shaped, 5 or 6 ft. long, with the gas inlet tube extending some distance down into the bottle. (See Fig. 6.)

At normal capacity, about 3,000,000 cubic feet per day of scrubbing water is pumped to the 12 towers by 6 centrifugal pumps direct connected to motors (180 kw., 1,480 r.p.m.). On each pump-shaft is connected a Pelton-type water wheel through which the exit water from the towers discharges and returns about 60 per cent of the input power, the motors furnishing the difference. Each pump and water-wheel set serves two towers, although there is a manifold cross-connecting all sets. The water feed to the Pelton wheel is controlled manually with the aid of a sight gage which indicates the level of water in the tower. Automatic float chambers for maintaining the proper water level and rate of discharge have recently been developed. The carbon-dioxide gas released in the water wheels passes to a holder for use in the ammonia utilization processes.

The gases liberated from the discharge water represent nearly all of the carbon dioxide in the original gas, the scrubbed gas retaining less than one per cent. All of the hydrogen sulphide and similar constituents are also removed. The solubility of the other gases is not negligible and experience at Oppau indicates that 7 to 8 volumes of hydrogen and nitrogen are dissolved while removing the 28 to 29 volumes of carbon dioxide. This absorption of hydrogen and nitrogen is about twice that called for by the available data on relative solubilities, but is in accordance with experience at Sheffield. It is interesting to note that the loss of hydrogen and nitrogen in the water is rather independent of the pressure at which the scrubbing is done, since the ratio of solubilities of the gases is not greatly affected by pressure.

Carbon-Dioxide Removal at Sheffield

Carbon dioxide was absorbed at Sheffield at 100 atmospheres pressure, which was the pressure maintained throughout the rest of the process. The compression was accomplished in the operating unit by one (and one spare) 4-stage compressor (4-12-34-100 atmos.) with 700 cu. ft. per minute low-pressure displacement. After allowing for water vapor in the gas, normal gas losses in scrubbing and purification, later "purge" of gas in the circulating system, and unavoidable but expected leakage, this displacement has a capacity of but 5 tons of ammonia per day. The compressors were belt driven by 300-hp. motors and operated very satisfactorily.

The original plan and installation was for water scrubbing the gas in three stages, the gas passing up through each of the three towers consecutively while fresh water was pumped to the top of each tower, fed downward through the packing, and was discharged into a common manifold. Such an arrangement for 3-stage scrubbing is fundamentally inefficient. It is evident that the water in the first tower will dissolve carbon dioxide with a minimum solubility corresponding

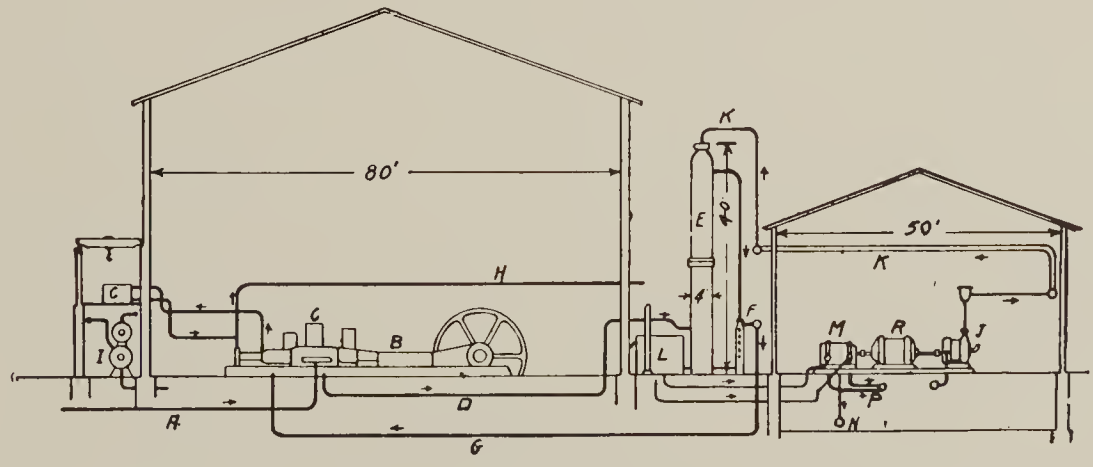


Fig. 6—Compressors and Water Scrubber at Oppau

A, compressor intake; *B*, 5-stage compressor; *C*, intercoolers; *D*, compressor exit 3rd stage; *E*, water scrubbers; *F*, mist trap; *G*, return of gas to 4th stage; *H*, gas exit 5th stage; *I*, boilers on gas engine exhaust; *J*, centrifugal pump; *K*, water inlet to scrubbers; *L*, reservoir on water exit; *M*, Pelton wheel power recovery; *N*, water discharge from Pelton; *P*, released CO_2 exit; *R*, motor for pumps.

to the initial partial pressure. The unit absorption capacity of the water in the second tower will then be decreased, due to the decreased partial pressure of carbon dioxide and finally in the third tower the solubility coefficient will be very low. In other words, at a given total

pressure the quantity of water necessary to dissolve a given weight of carbon dioxide increases with any decrease in the percentage of carbon dioxide. Thus, if instead of absorbing the carbon dioxide in three stages, it were all absorbed in one tower of sufficient capacity, all of the water would be used under optimum conditions. The latter operation may require but half the water of the former, and in addition will proportionately decrease the loss of the valuable gases by solution in this water. The attempted operation at Sheffield also involved many mechanical difficulties in the control of the parallel water supply and discharge from each of the towers. After two months of experimentation two of the towers were superimposed, making one tower 2 ft. in inside diameter and 30 ft. high. One-stage scrubbing in this tower led to very satisfactory results, leaving less than one-tenth of 1 per cent of carbon dioxide in the gas. The exit gas passed through a catch-pot to separate suspended water before passing to the next step of the process. (See Fig. 7.)

The packing in the towers is of prime importance for efficient scrubbing, since it is essential that it affords much contact surface, causes turbulent flow of the gas, does not pack or mesh together to

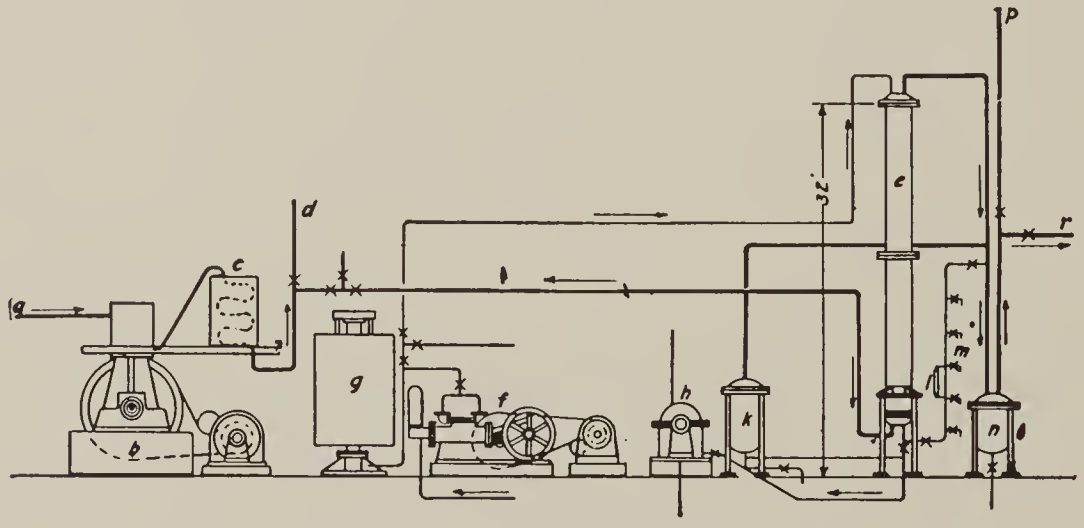


FIG. 7—Compressors and Water Scrubber at Sheffield

a, compressor intake; *b*, 4-stage compressor; *c*, cooler; *d*, gas vent from system; *e*, water-scrubber tower; *f*, hydraulic pumps; *g*, accumulator; *h*, Pelton wheel; *k*, float chamber; *l*, Klinger gages; *m*, tell-tales; *n*, catch pot; *p*, gas vent from system; *r*, gas exit to caustic system.

cause channeling of the fluids, and, finally, is resistant physically and chemically to the action of pressure and corrosion. At Sheffield, spiral tile were first tried, then pipe nipples, large hard pebbles, and special coke, but these were all found unsatisfactory. Finally small castings of special, though simple shape, were developed and proved successful.

The water was fed to the tower by one (and one spare) reciprocating motor-driven pump of 20 cu. ft. per minute displacement. The water discharge from the tower was through a Pelton water wheel driving a generator which fed into the power line. The water wheel operated on water at 1,500 lb. pressure and carrying about 20 volumes of dissolved gas. It was the source, therefore, of much trouble; at its best it returned but 25 per cent of the power in the water. The carbon dioxide released was discharged to the roof, and the water passed to the sewer. No utilization of the carbon dioxide was considered.

The question as to what pressure should be used for water scrubbing is one to be decided according to the conditions at the plant concerned. The quantity of water handled, of course, decreases with increase of pressure, since the solubility of carbon dioxide increases. The power required to pump the water is, however, not much affected, since as the quantity decreases its pressure head increases. Power recovery from the discharge water is much improved at the lower pressures, the main difficulty at very high pressure being due to the high nozzle velocities and the large quantities of gas expanding out of solution in the nozzle. Further, all the power required to compress the carbon dioxide to the scrubber pressure is a loss which is reduced by decreased pressure. High-pressure scrubbing decreases the size of the apparatus, since the volumes of gas and water are decreased proportionately while the velocity of absorption is increased. The advantage of smaller apparatus is, however, somewhat offset by the necessary increased strength of the vessels and joints. These considerations in general point to a comparatively low scrubbing pressure (*i.e.*, 200 to 500 lb. per sq. in.).

Carbon-Monoxide Removal at Oppau

As previously stated, the exit gas from the 12 water scrubbers returns to the 12 high-pressure gas compressors and is compressed to 200 atmospheres. The balance of the process beyond this point operates at this pressure. The next step consists of scrubbing the gas with a copper solution; the gas passes through scrubbers similar in operation to the water scrubbers, but using ammoniacal cuprous formate solution (containing perhaps some carbonate) at ordinary temperatures as the dissolving medium. Refrigeration of the solution and absorption of the carbon monoxide at low temperatures has ap-

parently been tried at Oppau and abandoned. There are 15 towers, arranged in two sets (of 7 and 8 each), and situated in one row along the outside of the compressor building. (See Fig. 8.) Any tower can be cut out and it is probable that one item in each set is a spare. The towers are steel forgings about 40 ft. high and 1½ ft. inside diameter, with walls 5 in. thick. They are heterogenously packed

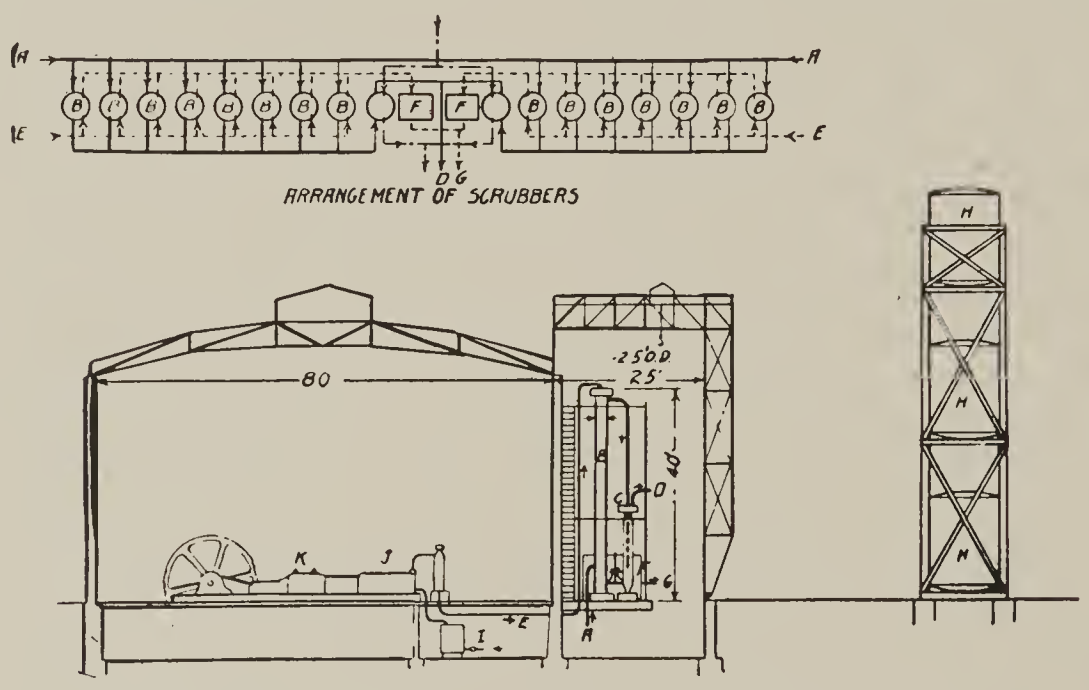


FIG. 8—Copper Solution Scrubbers and Pumps at Oppau

A, gas inlet to scrubber; *B*, scrubbers for Cu solution (see arrangement above); *C*, mist trap; *D*, purified gas exit; *E*, Cu solution exit from pump; *F*, pressure release tanks; *G*, Cu solution to regenerators; *H*, regenerating tanks; *I*, Cu solution inlet to pumps; *J*, Cu solution pumps; *K*, steam engine cylinders.

with iron Raschig rings (1 by 2 in. in diameter). A mist trap, similar in construction to that used in the water scrubbers, is employed at the exit of each tower.

CONTROL OF OPPAU COPPER-SOLUTION SCRUBBERS

All of the towers operate in parallel, the flow being manually controlled with the aid of sight gages. The gas inlets and exits of the scrubbers are cross-connected by a manifold and the operating valves are controlled from the inside of the building adjoining, the stems of the valves extending through the walls. There are friction orifices at the entrance of each tower for measuring the flow of gas, and the pressure differences are observed by means of a pressure balance of special construction. The device consists of a mercury U-tube of high-pressure pipe, bent to a semicircle. This circle is suspended at

its center on a knife edge with pressure connections of spiral flexible metal tubing leading from the center. A tendency to change the level of the mercury swings the U-tube and an adjustable counterweight about the knife edge. A pointer attached to the apparatus operates on a calibrated scale or a recording device.

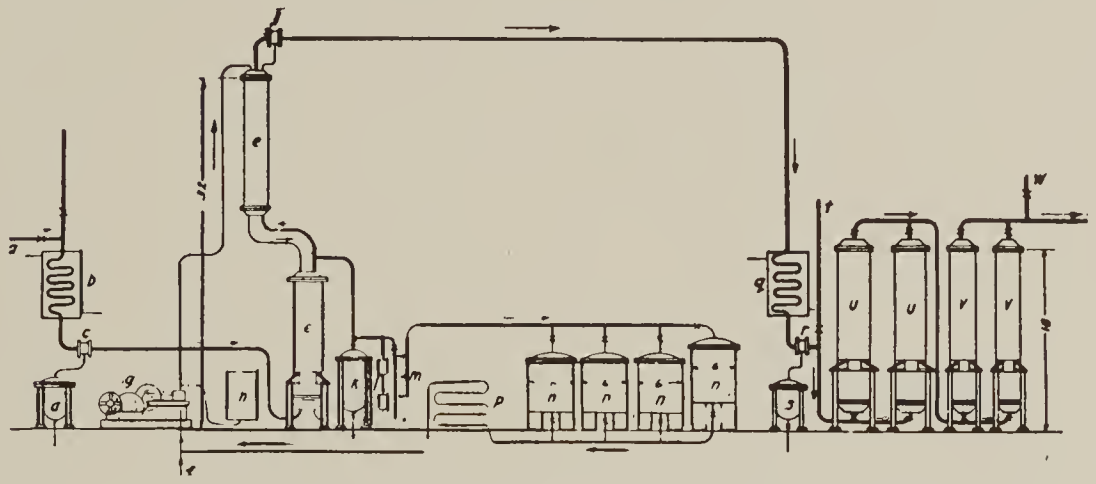


FIG. 9—Copper Solution Scrubbers and Driers at Sheffield

a, gas inlet from caustic system; *b*, cooler; *c*, separator; *d*, receiver; *e*, copper scrubbers; *f*, copper solution intake to pumps; *g*, copper solution pumps; *h*, accumulator; *j*, separator; *k*, float chamber; *l*, Klinger gages; *m*, tell-tales; *n*, regenerating and storage tanks; *p*, cooling coils for copper solution; *q*, cooler; *r*, separator; *s*, receiver; *t*, gas vent from system; *u*, driers; *v*, purifiers; *w*, gas vent from system; *x*, gas exit to circulating system.

The cuprous formate solution is pumped into the top of the scrubbers by 15 tandem-steam-driven pumps cross-connected in pairs (two pumps per flywheel). The solution passes from the bottom of the scrubbers to pressure release vessels, of which there are two, one for each set of towers. The spent solution, after release of the pressure, passes on to a large regenerating system where its carbon monoxide is removed by heating the solution under vacuum in regenerating vats, which are 20 ft. high and 16 ft. in diameter. The composition of the solution is readjusted before it is again used. The effluent gases from the generating system contain perhaps 50 per cent of carbon monoxide, the remainder being largely nitrogen, hydrogen, and ammonia. This mixture during the war was purified by additional ammoniacal copper solution and then piped to Ludwigshafen for the manufacture of phosgene, which was one of the important poison gases.

Scrubbing the gas with the ammoniacal cuprous solution removes, by reaction with the reduced copper, any free oxygen that may be present; by combination with the free ammonia it removes the residual

carbon dioxide as well as traces of other acidic gases that may have passed through the water scrubbers; and it absorbs nearly all of the 2 per cent of carbon monoxide in the gas. In normal operation about 35,000 cu. ft. per day of copper solution are passed through the towers, removing the carbon monoxide of the gas down to a few hundredths of one per cent. There is dissolved perhaps one per cent of the nitrogen and the hydrogen, which is liberated with the carbon monoxide on the regeneration of the solution. The absorption capacity of the solution for carbon monoxide is about 20 cu. ft. (60 deg. F. 30 in. Hg) per cu. ft. of solution, and regular operation approximates full saturation. There was, therefore, available at Oppau about 650,000 cu. ft. of carbon monoxide per day.

The question naturally arises why the copper scrubbing should be done at 200 instead of 25 atmospheres pressure. The mechanical construction would certainly be simpler for the latter. This case is different from that of the water scrubber. The power loss due to dissolved gas is slight and the energy requirement for the solution is small, so no attempt is made to recover the power. Further, the completeness and efficiency of purification is greatly improved by pressure and this is of paramount importance here. It must be remembered that the manufacturing and regenerating cost of the copper solution makes it desirable to use it in minimum quantities.

Carbon-Monoxide Removal at Sheffield

The original plan at Sheffield was to remove most of the carbon monoxide by scrubbing with hot concentrated caustic solution (according to the reaction: $NaOH + CO = NaCOOH$) preliminary to the scrubbing with the cuprous solution. The equipment for hot-caustic scrubbing was necessarily very elaborate. A gas-fired tubular heater was installed for heating the gas before it came in contact with the hot caustic. The hot gas passed on to the "lift line," where, acting as an air-lift pump, it carried hot-caustic solution to the top of the scrubber down which the gas and caustic passed over cast-iron packing. The scrubber tower was kept hot by a hot-air jacket supplied by a special gas-fired furnace. The liquid and gas, descending to the bottom of the scrubber, separated in a caustic-solution reservoir; the gas passed out through water-cooled coils for condensing the moisture, which drained back to the caustic reservoir. The solution in the reservoir returned by gravity to the inlet of the lift line to

repeat its cycle, but on the way passed through a gas-fired tubular furnace for reheating. For continuous operation partly spent solution was to be drawn from the reservoir, and fresh solution was to feed into the system through still another gas-fired furnace.

Since the hot-caustic scrubbing was finally abandoned it will not be necessary to discuss the principles involved. The intermittent trial runs proved that 75 per cent of the carbon monoxide can be removed by hot caustic. Cuprous-scrubbing is still required for the residual carbon monoxide, and the only net saving by hot caustic is a 75 per cent decrease in the circulation quantity of copper solution. It is doubtful whether hot-caustic scrubbing is economical even if its mechanical difficulties are overcome. The difficulties with the installation at Sheffield finally proved themselves insurmountable and after three months of untiring attempts, hot-caustic scrubbing was abandoned and the carbon monoxide allowed to pass on to the cuprous system for entire removal there. The caustic circulating and lift system, however, remained in service and although a cold solution was used it served to remove residual carbon dioxide, hydrogen sulphide, etc., after the water scrubbers.

Sheffield used cuprous ammonium carbonate instead of the formate for the absorption of carbon monoxide. There seems to be very little difference between the two as to absorptive power for carbon monoxide, but there is considerable advantage in using the formate when stability of the solution is taken into consideration. The carbonate as used at Sheffield gave much trouble in preparation, precipitated metallic copper while in use, broke down considerably on regeneration, and in general proved unsatisfactory.

Control of Cuprous Scrubbing at Sheffield

The original installation for cuprous scrubbing in Unit No. 1 consisted of one tower 2 ft. inside diameter and 15 ft. tall. The solution was supplied to the top of the tower by a small piston pump drawing from the storage vats and feeding through a "reducing chamber" filled with metallic copper in order to make sure that all the copper in the solution was in a reduced state. It was soon found that the solution required no reduction in operation, the carbon monoxide in solution acting as a reducing agent on regeneration even after the solution had picked up considerable quantities of oxygen during scrubbing. Further, it was found that one tower afforded insufficient

scrubbing and two were used, these being placed one above the other, though not directly superposed and so piped together as to operate as one long tower. (See Fig. 9.) The building and location of equipment did not permit setting up a single long tower. The gas passed upward through the towers and through a separator and catch-pot to entrap suspended liquid. The solution passed down the towers and out at the bottom, the discharge being controlled manually with the aid of sight gages, showing the level of liquid in the bottom of the tower. Automatic float chambers installed at Sheffield for controlling the discharge failed to function properly and no alternative from manual control was possible. In the redesign of the plant, an electrical device has been developed which tests indicate should operate very satisfactorily for the automatic control of the various liquid discharges throughout the process.

The copper solution was discharged directly through a line into the regenerating and storage tanks, where it was heated to 70 deg. C. at atmospheric pressure by steam coils and allowed to cool by radiation; no heat interchanger system was installed. Great care was taken in regeneration to avoid contamination of the solution by oxygen of the air. Heating this solution at atmospheric pressure was very destructive and required continuous readjustment of composition (especially the addition of ammonia).

Effect of Refrigeration

In view of the fact that refrigeration of the gas for removal of moisture was to follow the copper system at Sheffield, a beneficial change was made during operation to bring part of the refrigeration into effect together with the copper scrubbing. The gas before entering the copper scrubber passed through coils cooled by refrigerated brine. The copper solution on the way to the pumps was also cooled by brine. Although refrigeration does not greatly increase the absorption capacity of the solution at saturation, it does decidedly decrease the carbon monoxide vapor pressure of the solution when it is but partially saturated. Thus, refrigeration does not materially decrease the quantity of solution to be used, but does improve the purity of the gas at the exit of the copper towers where it is in contact with fresh solution.

The gas at Sheffield entered the copper scrubbers with about 4 per cent of carbon monoxide while the exit showed but a few hundredths

of one per cent. The methods of analysis for such small concentrations of carbon monoxide in hydrogen were very unsatisfactory and led to considerable uncertainty in operation. The absorption capacity of the solution as used was about 15 cu. ft. of carbon monoxide per cubic foot and 90 per cent saturation was easily obtained (calculated from the quantities of solution used and the volumes of gas scrubbed). The gas entering the scrubbers sometimes contained as much as 0.1 per cent of oxygen which was completely removed by the copper solution and taken care of by reduction during regeneration.

Additional Purification at Oppau

Following the copper scrubbers there are two caustic scrubbers, one in series for each set of parallel copper scrubbing towers. These two towers with mist traps are in the same row and identical in construction with the copper towers. About 3,500 cu. ft. of 30 deg. Bé. solution is circulated per day through the two scrubbers by means of two vertical duplex pumps with 40-hp. motors. It would seem that the caustic scrubber ordinarily aids little in purification but acts as a safety in the line in case the water scrubbers or copper scrubbers do not function properly. Partially spent caustic solution after release of pressure is handled by centrifugal pumps discharging to the final absorption tower of the nitric acid system.

This completes the purification steps in use at the Oppau plant. No precautions are taken to remove moisture, since, as we shall see, the ammonia synthesis system to which the gas passes directly from the caustic scrubbers utilizes water as the scrubbing medium to remove the ammonia from the gas. No steps are taken for removing the very small percentages of carbon monoxide and ammonia that are retained in the gas after leaving the scrubbers.

Additional Purification at Sheffield

It was necessary to desiccate the gas thoroughly at Sheffield in order to protect the particular type of ammonia catalyst selected for use there. This was accomplished by refrigeration followed by soda lime drying. For the former the gas passed through two sets of coils each submerged in a bath of refrigerated brine circulated by a small pump from an ammonia refrigerating system. In later operation, as previously noted, one of the brine coolers was reconnected to precede the copper system. The brine coolers worked very satisfactorily, the only care necessary being to avoid too low a temperature

which might freeze the condensed moisture within the coils. The gas passed from the coolers through separators and then upwards through a tower, 15 ft. high and 2 ft. in inside diameter, filled with coarse soda lime. There were two such towers, one being a spare to be repacked while the other was in use.

A tower filled with a special purification material, developed as a specific protection against poisons especially dangerous to the catalyst, followed the soda-lime towers. This completed the purification at Sheffield and the gas passed directly to the circulating system for ammonia synthesis.

The purified gases at Oppau enter the circulating system at about 200 atmospheres pressure, there mixing with the gases in circulation, and all pass on to the ammonia catalyst bomb for synthesis. The gas passes through three heat interchangers, two detached and one within the lower half of the catalyst bomb, after which the heated gas passes down through the catalyst bed, back through the heat interchangers, and then through a mist or dust trap, and finally goes to the ammonia absorption installation.

The ammonia synthesizers are arranged in sets, each consisting of the catalyst bomb or ammonia converter with heat interchangers and mist trap. Each set has a rated capacity of about 20 tons of ammonia per day. There are 15 such sets in the main installation at Oppau. They are arranged in a row, set partly below ground level, along, but outside of the wall of the building housing the pumps and special apparatus of the ammonia absorption and circulating systems. The valves, gages, pyrometers and other controls for the ammonia-converter sets are all located within the building. Over the row of converter sets is a protecting steel structure with a 70-ton traveling crane and between the respective converter sets is a brick wall. Thus a separate enclosure is built up for each set.

The Ammonia Converters at Oppau

The following important features are to be noted in the construction of the converter itself. The shell is 3½ ft. in outside diameter and 40 ft. high, and is made up of two 20-ft. sections bolted together at the middle. Continuous throughout the length of the two sections is a close-fitting steel liner which serves to protect the pressure casing from the action of the gases. The casing is a steel forging, with wall 5 in. thick, perforated radially with ⅛-in. holes spaced about a foot

apart. These serve to release gases diffusing through the liner, but allow the casing to carry all of the necessary mechanical stresses. To decrease still further the action of the gases, a later modification of the converters carries an additional liner small enough to leave an annular space between it and the outer liner, and during operation nitrogen under pressure is flushed through this space. Within the liners there is about 2½ in. of heat insulation built up of radial refractory brick. In the upper part of the enclosed chamber is the catalyst container, while in the lower is a heat exchanger. The catalyst is held in an annular space within a tube about 1½ ft. in diameter and around a 4-in. pipe leading the gas from the heat interchanger directly below to the top of the catalyst. The gas passes down through the catalyst and back through the heat interchanger.

The heat interchanger within the converter consists of a nest of about 150 half-inch, thick-walled tubes fastened into headers at each end and passing through baffle plates placed at right angles to the tubes every few inches throughout their length. This nest is placed within the converter shell in such a way as to carry the inlet gas up through the tubes and the catalyst exit gases through the baffled spaces outside the tubes. After assembling and charging the converter shell, the heads, which in reality are tapered plugs making a steel to steel seat, are forced into position by a hydraulic ram and are bolted into place with sixteen 3½-in. bolts while the ram pressure is still on. The whole bomb (catalyst and heat interchanger) is well lagged by an external insulator so adjusted that air may be circulated between the lagging and the shell for temperature control.

These complicated constructions are necessary for three distinct reasons: (1) The tensile strength, proportional limit, and the other important structural properties of steels, although slightly increasing up to a temperature of about 350 deg. C., rapidly and dangerously decrease with increase of temperature above that value. (2) Hydrogen at high temperature quite readily diffuses into and through steel and within the steel combines with carbon to form methane, which is not diffusible, thus causing blisters, blowholes and dangerous imperfections. (3) Ammonia at temperatures of formation or decomposition has a powerful action on iron, tending to break down completely its crystalline structure, probably by nitrification.

The two detached heat interchangers carry the same type of tube nests as previously described, but the shells are not built for internal

heat insulation or nitrogen circulation. The casings are less than 3 ft. in outside diameter by 25 ft. high, forged in one piece and equipped with liners. The mist trap at the exit of the interchangers is of much the same construction as that described for the water scrubbers. The inlet or cooler gases pass through the heat interchangers around the outside of the tubes, while the hot returning gases pass through the tubes. This is obviously the most efficient path.

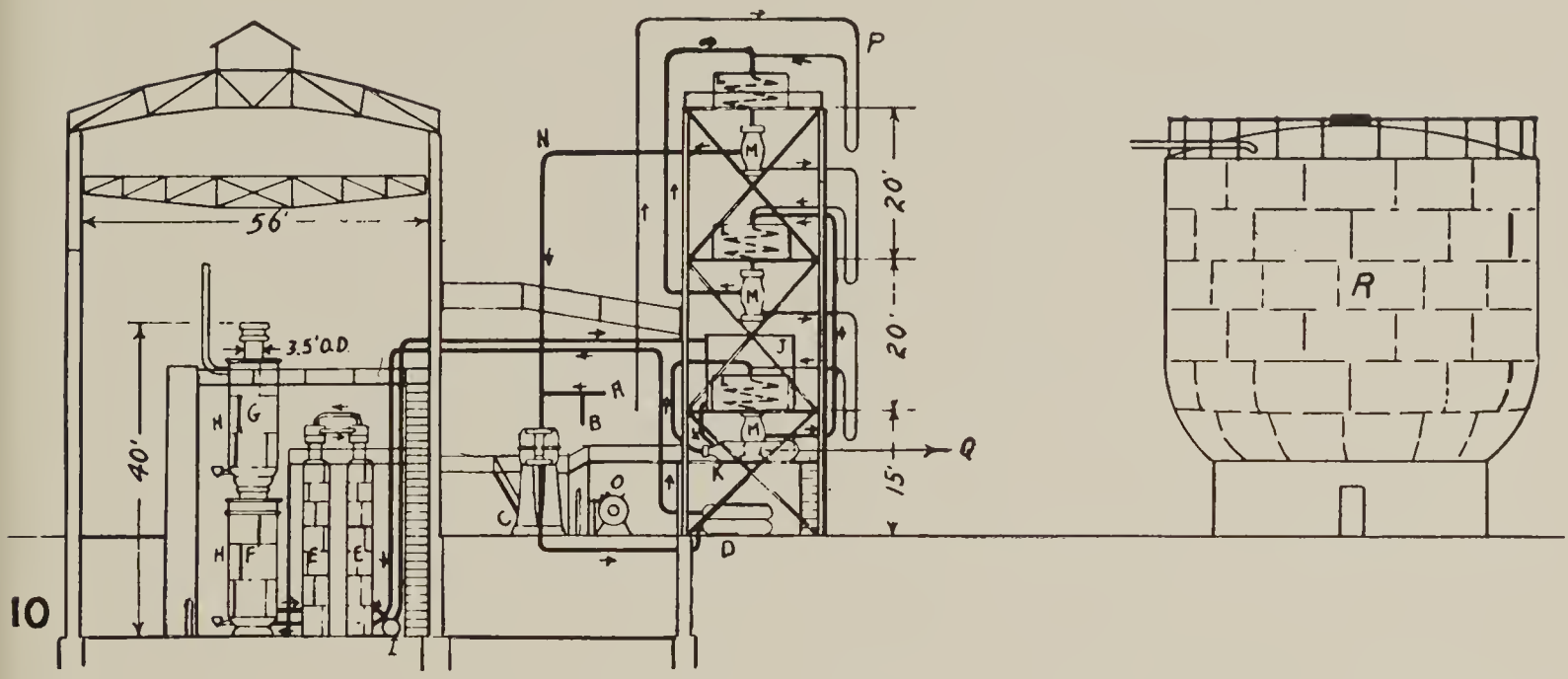
Operation of the Oppau Converters

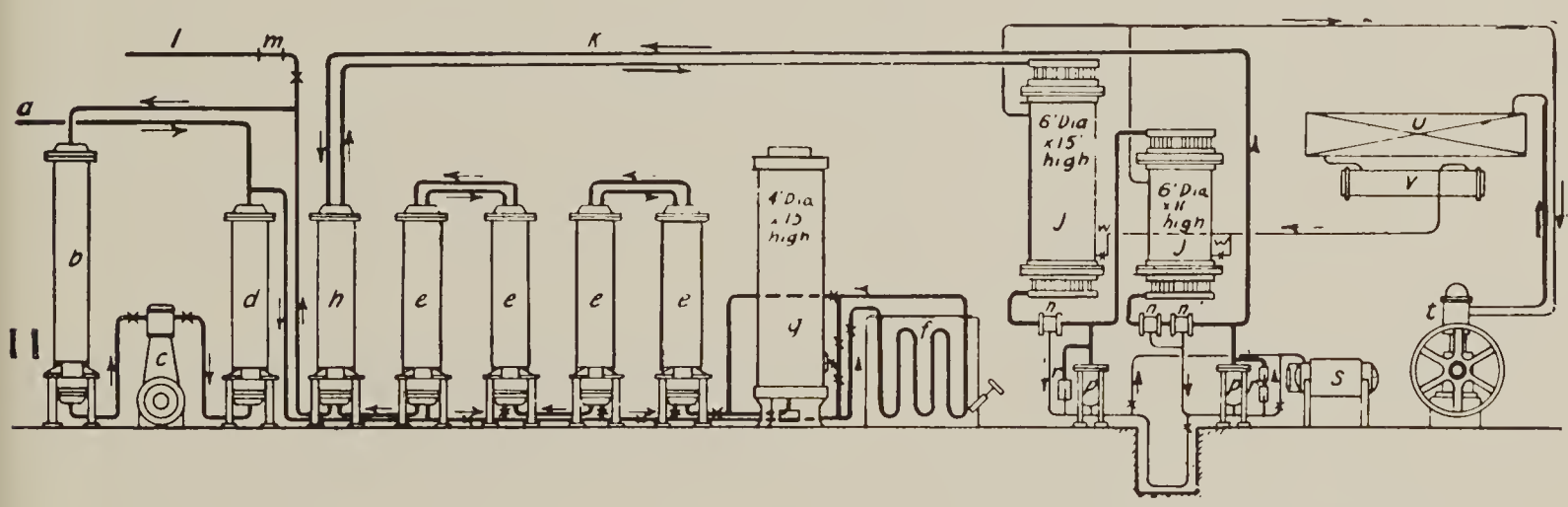
The catalyst bombs are charged with about 20 cu. ft. of a catalyst developed for the particular operating conditions at Oppau and consisting of practically pure iron specially prepared with an addition of some promotor. The material as used is about ½-in. mesh. Such a catalyst charge, when in use, produces about 20 tons of ammonia per day, or one ton per day per cu. ft. of catalyst. Operating at 5 per cent, this calls for a space velocity of 40,000 cu. ft. of free gas per hour per cu. ft. of catalyst, and a time of contact (allowing 33 per cent voids) of about one minute within the bed of catalyst.

The matter of the proper speed or space velocity at which to operate a catalyst is of great importance. As the speed is increased the percentage of ammonia in the exit gas is decreased, though not in as great a proportion; thus there is a greater total yield in weight of ammonia. Although this yield of ammonia controls the capacity of the catalyst, still the percentage of ammonia controls the temperature rise due to the exothermic reaction and this is an important factor in the operation of the heat exchangers and in the temperature maintenance of the system. And further, the percentage of ammonia controls the number of times a given quantity of gas must be recirculated before complete synthesis, and therefore governs the size of all the apparatus in the entire circulating system.

The concentration of ammonia produced at Oppau sometimes reached 5 to 6 per cent, but the general average in operation is probably about one per cent less than this figure. It is noteworthy that this represents a relatively incomplete attainment of equilibrium. The rise in temperature due to the exothermic reaction is 75 to 90 deg. C., for a concentration of 4 to 5 per cent of ammonia. This represents the heat available for maintaining the temperature of the system and also supplying the temperature head for heat interchange.

With only this small heat development the system at Oppau is





FIGS. 10 AND 11—Apparatus for Ammonia Synthesis and Removal at Oppau and at Sheffield

FIG. 10. Ammonia converters and absorbers at German plant. *A*, purified gas inlet to circulating system; *B*, pure nitrogen for adjustment of composition; *C*, circulating compressors; *D*, water and oil traps on compressor exit; *E*, heat exchangers; *F-G*, converter bomb (*F*, heat exchanges; *G*, catalyst chamber); *H*, insulator and ventilator around bomb; *I*, mist trap exit converter system; *J*, cooler before absorption; *K*, mist trap exit cooler; *L*, absorbers; *M*, separating bottles after absorbers; *N*, gas return after absorption; *O*, water pumps for absorbers; *P*, water injection to absorbers; *Q*, aqua ammonia exit to storage tanks; *R*, aqua ammonia storage tanks.

FIG. 11. Ammonia converters and liquefiers at American plant. *a*, purified gas inlet to circulating system; *b*, equalizer (return receiver for unconverted gas); *c*, circulating compressors; *d*, filter; *e*, heat exchangers; *f*, heat (gas-fired brick furnace); *g*, converter bomb; *h*, cold exchanger; *j*, liquefiers; *k*, gas return from liquefiers; *l*, gas vent for purging system; *m*, Venturi meter; *n*, separator (liquid ammonia); *p*, catch pot; *r*, Klinger gages; *s*, receivers (liquid ammonia); *t*, compressors—refrigeration; *u*, condenser; *v*, receiver; *w*, expansion valves; *z*, suction return to compressors.

probably not self-maintaining in temperature and addition of heat by internal combustion within the bomb is resorted to. The combustion device is also used to start the system when cold. Oxygen (or pure air) under pressure and hydrogen (or the reaction mixture) are supplied through a burner and igniter of special and very neat construction, which projects through the top of the catalyst bomb and maintains a flame in the direct path of the gases just before entering the catalyst bed. The moisture formed by combustion passes on through the catalyst with the reaction gases. One per cent of moisture by combustion will represent a rise in temperature of about 75 deg. C.

Effect of Moisture on the Catalyst

The effect of moisture on the catalyst is a point to be considered very seriously. Since at Oppau water scrubbing is used to remove ammonia from the gases after reaction, all the circulating gases carry some moisture. Saturation at room temperature calls for about 0.01 per cent by volume, but even this makes entirely unusable certain catalysts which, with dry gases, might be highly active and desirable. The type of catalyst developed at Oppau can remain in action in the presence of moisture, although its activity in such an atmosphere is greatly decreased and its operating temperature must be increased. The extent of the inhibition of catalysis depends on the moisture content. The ammonia equilibrium for 200 atmospheres pressure and 500 deg. C. calls for 17.6 per cent of ammonia, with probably 10 per cent of ammonia available from the catalyst when operating on pure gas and at the velocities in use at Oppau. Actual operation with moisture of combustion results in less than one-half this amount and further reduces the heat generation within the bomb and the temperature head across the heat interchangers, thus making it increasingly more difficult to maintain the necessary temperature. To obviate the effect of such a cycle considerable experimenting is being done at Oppau, looking toward the development of an electrical heater to operate in place of the oxygen burner. Such a new device would have, as additional advantages, increased safety, no loss of pure hydrogen, and better temperature regulation.

In addition to the 15 converter sets, there is still available for operation at Oppau an older installation from which the present plant was developed. This consists of 8 much smaller converter sets, the catalyst bombs being only 1½ ft. in outside diameter by 30 ft. tall.

These bombs are started by external heating applied by combustion of producer gas in a surrounding jacket. Some of this heating is also maintained during operation. This is obviously a dangerous procedure. This old installation connects into the main feeder lines and the exit manifold of the large installation, the ammonia gases passing to the next step, that of ammonia removal.

Ammonia Synthesis at Sheffield

The purified gases entered a high-pressure vessel or mixing chamber in the circulating system at less than 100 atmospheres pressure, there to mix with the gases in circulation. The mixture passed on through 4 heat interchangers, thence through a heater for starting or maintaining the temperature of the system, then through the catalyst bomb at 500 deg. C. and finally back through the heat interchangers.

There was but one set of interchangers and catalyst bomb in the operating unit (Unit No. 1) at Sheffield and this was located in the same building as the purification apparatus and equipment. The ammonia converter itself consisted of a chromium-vanadium forging 4 ft. in inside diameter, 15 ft. high, with walls 3 in. thick. Within this shell was a nest of ninety 2-in. boiler tubes, which were to be charged with 50 cu. ft. of catalyst. The gas entered at the bottom of the shell, passed up around the tubes, then down through the catalyst and out at the bottom of the shell. The heads of the converter were designed to make a special type joint with the shell, making use of the internal pressure to keep the joint tight; this device, however, proved troublesome and unsuccessful. Otherwise the entire construction was very simple compared to the bomb at Oppau. Within the converter, no arrangement was made to protect the bomb from the action of the gases, or to keep it cooler than the operating temperature.

The heat interchangers consisted of forged steel shells 2 ft. in inside diameter, 14 ft. high, with 3-in. walls. Within each shell there was a nest of tubes of very special construction. Each tube element of the nest consisted of 3 concentric tubes, thus having two annular spaces between them. The two gas flows interchanging heat passed each other through these annular paths. No use was made of the volume around the tube elements. This arrangement is ingenious and leads to a high coefficient of heat transfer per unit of transfer surface, but also leads to high friction per unit of heat transferred. Larger apparatus per unit of transfer surface is also required. By a

system of valves in the interconnections between interchangers, any one of the interchangers could be bypassed during operation.

Heating of the Gas at Sheffield

A heater, similar in type to a standard steam superheater, was situated so as to heat the circulating gases just before they entered the catalyst bomb. The gas flowed through a series of high-pressure tubes connected with flanged joints in a gas-fired furnace of three passes. This heater was the source of much trouble due to bursting tubes and leaking joints and prevented any continuous testing of the circulating system as a whole. This type of heating is subject to two inherent objections: (1) The heat transfer surface must operate at a high temperature and at the same time retain its strength. (2) The efficiency of a furnace furnishing heat at such a high-temperature level is necessarily very low. These two objections can be overcome only by internal heat application, which can be accomplished in two ways: (1) Internal combustion of hydrogen by injection of oxygen, and (2) electrical resistance heating directly in the gas path. These have been discussed somewhat under the Oppau description. Electrical heating during Sheffield operation could not have been more expensive than the method in use.

During attempted operation, the catalyst bomb was charged with a special catalyst "composed of iron, sodium and nitrogen." During the development of this catalyst, laboratory experiments with pure gas had indicated that at a space velocity of 5,000 cu. ft. of free gas per cu. ft. of catalyst about 8 per cent of ammonia might be expected in the gas. This catalyst was especially sensitive to poisons, and traces of oxygen-carrying impurities such as O_2, CO_2, H_2O, and CO permanently and rapidly deteriorated its activity. Such a catalyst may be highly active on pure gas, but commercial operation can not be expected to maintain the necessary purity of gases. In fact, at Sheffield, it is doubtful if the desired purity was ever obtained. Operation was so intermittent that statements as to the actual percentage of ammonia converted by the catalyst would be misleading.

Ammonia Removal at Oppau

The ammonia content of the gas is removed by water scrubbing the gas without releasing its pressure, the remaining gas recirculating while the absorbing water is discharged as aqua ammonia. The gas mixture with 4 to 5 per cent of ammonia leaves the converter sets

and passes to a main which feeds 8 absorber sets, located on the outer side of the pump-house building and opposite the converter sets. In order to secure more favorable temperature conditions for absorption each set first passes the gas through a cooler of 12 coils in parallel, thence to a mist separator and on to the elevated water absorbers. There are 3 absorbers in each set placed one above the other at 20-ft. levels. Each absorber consists of 12 spiral concentric coils connected in parallel, and submerged in a water bath in order to take up the heat of solution generated within the coils. At the exit of each absorber is located a trap to separate the gas and liquid. The water flows downward through the set of absorbers as a whole and the gas upwards, the absorption taking place in three stages, with separation of gas and liquid between stages. In the uppermost stage (third gas and first water stage) water is injected with the gas and the mixture of gas and liquid flows downward through the coils by gravity. The solution from the third gas stage after separation feeds downward to the second and then on to the first. The gas from the first and lowest stage flows to the entrance of the second stage, then on to the third. This arrangement affords a counter supply of solvent although the necessary parallel flow is obtained within the coils of each stage. A newer type of absorber has been installed and used for the last stage of one set of absorbers. This consisted of towers similar to those used in the cuprous formate scrubbing system and provided true counter-current flow at least in the last stage of absorption.

There are 6 steam-driven water pumps (totaling about 800 hp.) for the absorbers. This pump capacity will furnish sufficient water to the absorber sets to give as a final product commercial aqua ammonia of a strength of 25 per cent. Considerably less water may be used and solutions of much higher strength obtained, but upon release of pressure these evolve gaseous ammonia and leave a 25 per cent aqua. The solution leaving the last separator of the absorber system is discharged to high-pressure ammonia receivers, which in turn are discharged when full into closed low-pressure reservoirs. Considerable nitrogen and hydrogen gases are dissolved in the aqua and these, released in the reservoirs, are washed with a counter current flow of water to remove ammonia and are returned to the gas holder just previous to the compression stages of the process. The aqua ammonia is finally stored in three large tanks of about 750,000 gal. capacity each.

The high-pressure gas in passing through the absorber system

gives up most of its ammonia to the water, only about one-fourth of one per cent remaining in the gas. This ammonia content will depend on the temperature at which the last gas stage of absorption was maintained and on the ammonia concentration of the aqua emerging from this last stage together with the gas. Evidently the more water used for absorption the less is the residual ammonia in the gas. However, the hydrogen and nitrogen dissolved and the power required will increase with the increase of water and this represents some small loss in the efficiency of the system.

Ammonia Removal at Sheffield

The intention at Sheffield was to remove the ammonia from the gas by refrigeration at temperatures of —30 or —40 deg. C.; the ammonia was discharged as liquid anhydrous ammonia, while the residual gas was to recirculate back to the converter set. There were two ammonia liquefiers in the installation, each consisting of 7 spiral concentric coils fed from a common manifold and discharging into a common manifold. Inclosing these spirals was a shell 6 ft. in diameter by 15 ft. high, in which the necessary refrigeration was maintained. A standard-type ammonia installation furnished the refrigeration, the ammonia from the condensers expanded directly into the liquefier shells, and the compressors withdrew the evaporated ammonia from the top of the shells. The two liquefiers operated in series on the high-pressure gas, although the refrigeration on the outside of the coils operated in parallel in the two shells. The high-pressure gas on leaving each of the liquefier coils passed through a mechanical separator where the liquefied ammonia was separated and drained to a pot while the gas passed on through the separator, and thence to a cold interchanger. This apparatus was identical with the heat interchangers previously described and served to cool the incoming gases to the liquefiers by means of the cold gases leaving the system.

To maintain temperatures of —30 or —40 deg. C. it is, of course, necessary to expand the refrigerating ammonia to a considerable vacuum and it is required that the refrigerating compressors operate at that vacuum on the suction stroke. This, in turn, means that the compressors have a much smaller refrigerating capacity in view of the large volume of the refrigerant. It was soon found at Sheffield that although the compressors had the necessary rated refrigerating

capacity when operating to make ice under commercial conditions, still they had less than 20 per cent of the refrigerating capacity necessary for the ammonia removal. Additional compressors were, therefore, at once moved over from Units 2 and 3 at Sheffield, together with all spares, and all were connected in the line for operation in Unit No. 1.

The operation of single-stage ammonia compressors with ratios of compression of the order of 20 to 1 must, in general, lead to serious inefficiencies and mechanical difficulties. The operation of two liquefiers in series on the gas with refrigeration on each at the same low-temperature level is also inefficient. The first liquefier in the series could be operated to advantage at a higher temperature level and leave only the second liquefier to meet the low-temperature requirement. The Nitrate Division in its redesign of the Sheffield plant has laid out a simple installation with standard equipment to operate with compound compression of refrigerant for the low-temperature liquefier while the first liquefier operates within a nearly normal ice-making cycle.

The total refrigerating capacity may be considerably reduced, although the problem is not greatly simplified where ammonia liquid is not the necessary product of manufacture. In such cases the condensed liquid leaving this high-pressure system may be expanded into a liquefier shell, thus effecting considerable refrigeration. This refrigeration would be necessarily independent of the main refrigerating installation in view of the gases dissolved in the synthesized ammonia.

Separation of Condensed Ammonia at Sheffield

The separators for removing the condensed ammonia from the high-pressure gas at Sheffield consisted primarily of a vertical baffle plate at right angles to the horizontal flow of ammonia-laden gases. No data were obtained as to the efficiency of these simple separators, but general indications were that the ammonia removal was incomplete. The separated ammonia drained from the separator into a high-pressure receiver from which it was discharged at intervals into liquid ammonia reservoirs.

The removal of the condensed ammonia from the high-pressure gas is a subject requiring serious consideration. Much of the ammonia condenses in the gas as a fine mist difficult to precipitate or agglomerate into larger particles for separation. These in turn are

difficult to separate from the gas stream. An analogous but much simpler case is the separation of water from wet steam, which is accomplished in the industry by various types of apparatus, all of which depend on the difference in specific gravity between the suspended water and the steam. In the latter case, ordinary practice involves a ratio of specific gravities of the order of 150 to 1, whereas in the case of removing ammonia from the high-pressure gas the ratio is but one-tenth as great. In view of the low specific-gravity ratio, high velocities are probably essential in mechanical separation. Other requirements, no doubt, are low friction of the gas stream over the separating surfaces, and immediate removal of the separated liquid from contact with the gas. All the above has been kept in mind in the development by the Nitrate Division of an ammonia separator for use at Sheffield should the plant ever again operate.

The Germans, in developing their process, had seriously considered and experimented with refrigeration as a means of ammonia removal, but they finally turned to water absorption as the easiest solution of the problem. In so doing, they gave up several distinct advantages of refrigeration: (1) Circulation of pure dry gases in which desiccation is maintained by the precipitation of anhydrous ammonia within the gas. (2) Production of pure anhydrous ammonia accomplished without any further steps of distillation. The first of the above is the most important in view of the fact that moisture in the system decreases catalytic activity and reduces the capacity of the entire installation, as has been previously discussed. The second is important only in connection with the utilization of the ammonia. On the other hand, water absorption of ammonia has the advantage of practically complete ammonia removal, and decided reduction in power consumption.

Circulating System at Oppau

The gas is circulated through the converter sets and through the absorption system by 10 double-acting circulating pumps. These are steam driven and direct connected at 90 deg.; the pump cylinder is vertical and the steam cylinder horizontal. In normal operation the differential pressure necessary to circulate the gases is about 5 atmospheres, though it has, at times, risen to 10. The circulating pumps are located in the cycle just after the absorbers and ahead of the converter sets. At the inlet side of the circulating pump the pure make-

up gas is added and also the composition of the gas in circulation is adjusted by the addition of the pure nitrogen that was spoken of earlier in this paper.

The question frequently arises as to whether it is desirable to have the circulating pump precede or follow the point in the system where the make-up gases are added. In the latter case, the pump must directly handle the volume of make-up gas, together with the volume of circulating gases. However, the total pressure of the circulating system is higher by the amount of the differential pressure, since the pressure of the make-up is fixed by the pressure of the purification system. The pressure desired in the circulating system should determine the location of the circulating pump; the total quantity of energy expended is but slightly different in the two cases.

The speed of circulation of the gases as it affects the catalysis of the ammonia has been discussed in connection with space velocity under ammonia synthesis. For a given installation, operation may develop any one of the following limitations to an increase in the speed of circulation: (1) Insufficient heat transfer to maintain the temperature of the ammonia converter sets, (2) insufficient capacity of the purification system to supply the necessary gas for the increased yield, (3) insufficient capacity of the ammonia-removal installation to take care of the increased yield, and (4) excessive friction to gas flow in the apparatus of the circulating system. These general engineering aspects of the process are of fundamental importance, but their discussion is not within the purpose of this paper.

Inert Gases

The inert gases, methane and argon, are present to the extent of 0.5 to 0.7 per cent in the make-up entering the circulating system at Oppau, and tend to accumulate as the hydrogen and nitrogen are being removed in the form of ammonia. Some method of removal of this accumulation must be employed. The simplest method for continuous operation is to allow a fraction of the circulating gases to escape continually. Purging a quantity of gas from the circulating system equivalent to 5 per cent of the entering make-up gas will maintain a concentration of inert gases of 20 times that in the make-up. Likewise, 10 per cent purge will allow a concentration of 10 times that entering the system. The effect of inert gases on the catalysis of ammonia is very decided due to the lowering of the equilibrium,

but on the other hand, the loss of purified hydrogen and nitrogen in the purge is costly, although the hydrogen may be burned under boilers. In operation the choice as to the proper purge is generally fixed by the unavoidable leakage in the system. Thus, at Oppau, this was never below 10 per cent of the make-up gas, therefore the concentration of the inert was never above 5 to 7 per cent and no additional purge was necessary.

Circulating System at Sheffield

At Sheffield the gas exit from the liquefiers passed to the circulating pumps, the make-up gas connecting in at the exit of the pumps. The circulating pumps themselves were vertical, double acting, motor driven, but due to the sensitiveness of the catalyst, were not lubricated and therefore not equipped with piston rings.

This led to rather low volumetric efficiency. The pumps had been designed for a maximum differential of 50 lb. Due to the many right-angle elbows and tees, numerous valves, and the special construction of the heat interchangers, the friction in the system accumulated to 150 lb. and still less gas was circulated than was necessary. This caused considerable difficulty with the pumps and their motors. Engineering experience offers very little information for the calculation of friction of gas flow under the conditions existing in the synthetic ammonia process. Some preliminary experiments conducted by the Nitrate Division indicate that it varies with the square of the velocity and therefore that a formula of the standard type may apply.

There are no facilities for adjustment of composition in the circulating system at Sheffield, but during operation such adjustment was found unnecessary in view of the high losses, which at times amounted to 50 per cent. These losses of course prevented accumulation of either hydrogen or nitrogen in the system, as well as accumulation of the inert gases.

The pipe connections throughout the system were all made up with copper gaskets, which worked very satisfactorily where there were no undue strains on the joints. The apparatus in the circulating system was arranged very closely and there was no allowance for the expansion due to the extreme range of temperature. The strain thus set up always developed leaks. There were many valves in the heat interchanger connections and in other hot parts of the system and although these valves were water cooled, still the differential expan-

sion between the stem and the block caused difficulties. Operation on this portion of the system was, however, so intermittent and of such short duration that no opportunity was given to cure the difficulties encountered, although the matter has been taken up with great care in the redesign of the plant and in the development of joints and valves.

Construction and Operating Costs at Oppau

The entire construction cost chargeable to the Oppau plant will total perhaps 250,000,000 marks. If the original pilot plant, the coke plant, the ammonia-utilization plants—*i.e.,* ammonium sulphate, and nitric acid—be neglected and corresponding reductions made in the general facilities investment, the cost chargeable to the manufacture of ammonia alone is about one-half the entire cost, or some 125,000,000 marks. Of this about one-third is chargeable to buildings and construction, and two-thirds to equipment and machinery. The former includes buildings, foundations, roads, trackage, and all general construction; the latter covers special equipment or machinery and includes its installation cost. This is an estimate of actual pre-war (1914) cost and would mean an investment of about $270 per annual short ton of ammonia capacity, or $100,000 per daily ton. This cost applied only for the conditions existing in Germany at the time considered. In 1916, the construction costs at Merseburg showed an increase of more than 50 per cent over the Oppau figure in view of the rising labor and material charge. The 1918 estimate, based on the construction costs for the last one-fourth capacity of the Merseburg plant, had increased 150 per cent over the 1914 figure. (1914—$270; 1916—$400; 1918—$700.)

It is difficult to arrive at the labor necessary for operation. During the war there were at Oppau more than 6,000 workmen, not counting prisoners of war. This number was reduced after the war to about 5,000, directed by about 50 engineers through many superintendents and foremen. These figures include all departments of ammonia utilization, as well as construction, repair and maintenance. About 3,500 men and 35 engineers are employed normally in the manufacture of the ammonia, including repair and maintenance of the plant. Of this number about 2,500 are required directly on operation. The labor charge of 2,500 men represents about 66 man hours per ton. The wages paid at Oppau in 1914 might average about 0.6

mark per hour. By 1918, wages had gone up in about the same proportion as the construction costs above—*i.e.*, to 1.5 marks.

The only raw material necessary at Oppau is fuel. Estimates based upon reliable data indicate the following quantities of fuel per ton ammonia produced:

a. For water gas generators (Hydrogen production) *b*. For lean gas generators (Nitrogen production)	2 tons coke
c. For gas producers (Power and steam)	1 ton coal
d. For boilers (Steam and power)	2 tons lignite

The power and steam consumption is all included under (*c*) and (*d*). The power developed as such seems to be of the order of 3,000 kw. hr. per ton of ammonia. The steam developed by gas-engine exhaust or by boilers and consumed directly (not in steam engines) is perhaps 8 tons per ton of ammonia.

For the maintenance and repair charges (including materials and labor) we may assume 2 per cent per annum for buildings and construction and 8 per cent for equipment and machinery, which averages 6 per cent for the ammonia installation. For depreciation and amortization, we may allow 4 per cent for buildings and 7 per cent for equipment, which also averages 6 per cent for the installation. A charge for development and obsolescence is properly made on this type of plant and this has been allowed at 6 per cent on equipment and machinery only. As the process becomes more standardized and better developed this charge will decrease till it may be absorbed as depreciation and amortization, then taken at 10 per cent. These differentiations are delicate ones, since certain repair charges may be classed as depreciation while certain obsolescence charges may properly be classed with amortization. The total plant-upkeep charge per annum can be conservatively taken at 16 per cent of the investment for this type of installation.

	Buildings and Construction, Per Cent	Equipment and Macninery, per Cent	Average for Plant, per Cent
Maintenance and repair	2	8	6
Depreciation and amortization	4	7	6
Development and obsolescence	0	6	4
Total plant upkeep	6	21	16

In addition there are such fixed charges as interest, insurance, and taxes, which we may sum up at 9 per cent. The total for plant upkeep and fixed charges (25 per cent) represents over half the production cost of ammonia.

PLANT PRODUCTION COST PER TON OF AMMONIA AT OPPAU, GERMANY, IN 1914

	Marks	Dollars
Labor Operating:		
35 engineers at 10,000 marks per annum	3.2	
66 man-hours per ton at 0.6 mark per hr.	39.6	
	42.8	($10.27)
Fuel:		
2 tons coke at 20 marks	40	
1 ton coal at 15 marks	15	
2 tons lignite at 10 marks	20	
	75	($18.00)
Plant Upkeep:		
Repair and maintenance at 6 per cent.	68.2	
Depreciation and amortization at 6 per cent.	68.2	
Development and obsolescence at 4 per cent.	45.5	
	181.9	($43.66)
General Works Expense:		
Unclassified expenses, 10 per cent. of above	30	
Incidental materials, 5 per cent. of above	15	
	45	($10.80)
Fixed Charges:		
Interest, insurance, taxes (at 9 per cent.)	102.3	($24.55)
Total production cost per short ton of ammonia	447.3	$107.28
Total production cost per pound of ammonia	0.2235	0.05364

In the accompanying table is given an estimate for the cost of ammonia per ton as produced at Oppau in the form of aqua in 1914–1915, at the time the plant was developed. The cost in German marks for 1918, based on Merseburg experience and prices then existing, may be taken at about 2½ times the 1914 figure. The 1918 figure may be indicative of the present-day cost in Germany, although in view of the unsettled conditions and the prevailing rates of exchange any figures given for post-war conditions are to a large extent meaningless.

CONSTRUCTION COSTS FOR THE AMERICAN PLANT

The actual construction cost of the entire plant at Sheffield as built under emergency conditions was about $13,000,000. This in-

cluded the nitric-acid and ammonium-nitrate plants, as well as the village for housing the employees. Of the total amount, about $7,000,000 is chargeable to synthetic-ammonia manufacture if all else be neglected and proportionate deductions be made in general facilities. The plant was in many ways not completed and an additional $1,000,000 must be allowed for this purpose. This additional allowance does not consider the changes or improvements necessary for successful operation, but is to cover the incomplete installation of Unit No. 3 at the plant, the omission of properly equipped repair shops, and the future requirement of a laboratory and office building. The total of $8,000,000 represents costs under emergency conditions and may be reduced by 25 per cent for an estimate of normal construction costs at the close of the war. Based on the rated capacity of 10,000 tons per annum, the normal investment per annual ton of ammonia would thus have been about $600, which at first sight compares favorably with the later construction costs of the German plants. However, in making any comparison, the following points must be kept in mind: (1) The rated capacity of the Sheffield plant may not have been its production capacity. (2) The investment in Germany included gas producers, gas engines, etc., which were necessary there to reduce the power charges and which in the United States are in general not necessary. For purposes of estimating costs for present-day construction in the United States, we can not allow less than $400 per annual ton of ammonia for plants of capacities comparable with that at Sheffield.

Based on a $400 investment per annual ton of ammonia, plant upkeep and fixed charges will represent a cost of about $100 per ton of product. The additional cost for labor, materials (fuel, power, steam, water) and other direct operating expenses will be of a like magnitude. No attempt is made here to develop these latter costs since they would depend upon the specific conditions existing at any particular plant. The total plant production cost, whether it be $200 or $250 per ton ammonia, of course includes no distribution, sales, or main office expense. It is evident from this superficial survey of costs that improvements of efficiencies at different steps of the process, with corresponding slight reductions in fuel, labor or power consumption, will not in any large proportion decrease the cost of the product. Any great saving must be accomplished by the use of the by-product (carbon dioxide) from the process or by a reduction in the investment.

The only by-product from the process is carbon dioxide, which is available to the extent of 40,000 to 45,000 cu. ft. per ton of ammonia. Its utilization requires the installation and operation of some additional process using the carbon dioxide and preferably a process using the ammonia as well. This calls to mind, first, the ammonia-soda process, turning out as final products ammonium chloride and soda ash. This combination of processes is in every way logical, but not as simple as it might appear. Interdependence of the two processes will make operation increasingly more difficult. Although the by-product, carbon dioxide, would be of direct use in the ammonia-soda process, still lime would remain necessary for causticizing. The marketability and desirability of the ammonium chloride, as well as its preparation from the liquors, are also important factors. The complicating features just mentioned can be overcome in time should necessity require. A much less intricate, though less valuable, utilization of carbon dioxide is that for the double decomposition of gypsum in the presence of ammonia, yielding ammonium sulphate as the product and discarding the calcium carbonate. The German plants are using both of the above combinations, finding advantages in each. They have also experimented with the direct combination of ammonia and carbon dioxide for conversion to urea as the final product. The latter would be a very desirable solution of the entire problem of ammonia and carbon-dioxide utilization.

Some reduction in investment per unit production may be obtained by plants of very large capacities, but as long as these plants consist of multiple items of apparatus, each of comparatively small capacity, such reduction of investment can be only of a secondary order. Any large reduction in the investment must presuppose fundamental modifications of the process, as installed either in Germany or the United States. Such changes must be basic in character and represent definite reductions in the quantity or in the cost of equipment necessary for operation.

Concluding Remarks

The German process and combination of processes reached their present state of development with the financial aid of the government and under military pressure. As has been stated previously, a pilot plant had been built and preliminary experimentation completed by 1914, before the final construction and operation of the large Oppau plant to supply Germany's war needs. It is a question whether pri-

vate capital would have of itself invested such large sums in the Oppau and Merseburg plants in normal times or without governmental aid. It is a further question as to whether post-war conditions are as favorable for private capital as were the pre-war conditions. We know, however, that since the plants have been built and operated successfully during the war to produce large quantities of ammonia, those plants must continue to operate and furnish ammonia for home consumption and export. The cost figures from those plants may mean but little, for a great part of their construction cost and development has been written off as a war charge.

The synthetic-ammonia industry in this country is at present in a status similar to that in Germany at the time the pilot plant at Oppau was being developed, although there is not here the enormous pressure and stimulus for development that the government put behind the German installation. It would be obviously unfair to compare the experimental plant at Sheffield with anything but the original pilot plant in Germany. The main Oppau plant was the final development from the experimental stages through which any new and complex process must pass. Unless the Germans should take up actual construction in this country and make available their store of experience and knowledge, the industry in this country must develop its own industrial installation.

The Problem from Various Viewpoints

It is said that the industrial development of the direct synthetic-ammonia process is the greatest of modern chemical engineering problems. The true aspects of the problem, however, are somewhat beclouded by the difference in viewpoint of those following or aiding in its developments. The research chemist realizes quite rightly that the chemical problems involved are of the simplest nature except for the final step of catalysis of hydrogen and nitrogen to synthesize ammonia. He, therefore, feels that if he can develop an active and satisfactory catalytic material, the entire problem is in general solved and it remains but for the engineer to design and erect the plant. The designing engineer, on the other hand, feels that the development of a catalyst is a specific laboratory problem with which the research chemist is properly equipped to cope, but that the design of dependable equipment to operate at high pressures with temperatures at times approaching a red heat, and with gases or liquids sometimes

corrosive on the materials of construction, is the really serious obstacle to success. He is appalled at the lack of data and precedents at hand for his work and is certain that if he succeeds all else is relatively simple and it only remains to erect and operate the plant. The operating chemical engineer to some extent appreciates both the above viewpoints, since he must realize that his success depends on the success of both the chemist and the engineer, but he further feels that the determination and proper control of the many complicated and interdependent operating variables and steps of the process are in the last analysis the real basis of success. The industrial interests in control of commercial development have still another viewpoint. They appreciate only to a small extent the problem of the research chemist, the designing engineer, or the operating chemical engineer, but rightly feel that the success of the above men is for them a failure if the resulting investment, fixed charges or operating expenses make the cost of the product prohibitive.

Successful development of the synthetic-ammonia process can be attained only by a full appreciation of all the above viewpoints properly weighed against one another and by a most conscientious cooperation among the chemists, engineers, operators and executives. A new plant availing itself of the experience gained in operation at Sheffield, and of information obtained since then, should show very great improvement over the Sheffield plant, and there is no reason why the process could not finally be developed successfully in this and other countries as well as in Germany, if the demand for the product is sufficient to justify the investment.

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